U.S. DEPARTMENT OF
ENERGY

Office of
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RENEWABLE ENERGY

2017 Wind Technologies Market Report: Summary

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2017 Wind Technologies Market Report

Purpose, Scope, and Data:

- Publicly available annual report summarizing key trends in the U.S. wind power market, with a focus on 2017
- Scope focuses on land-based wind turbines over 100 kW
- Separate DOE-funded reports on distributed and offshore wind
- Data sources include EIA, FERC, SEC, AWEA, etc. (see full report)

Report Authors:

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- Contributions from others at Berkeley Lab, Exeter Associates, National Renewable Energy Laboratory

Funded by: U.S. DOE Wind Energy Technologies Office

Available at: http://energy.gov/windreport

Report Contents

- Installation trends
- Industry trends
- Technology trends
- Performance trends
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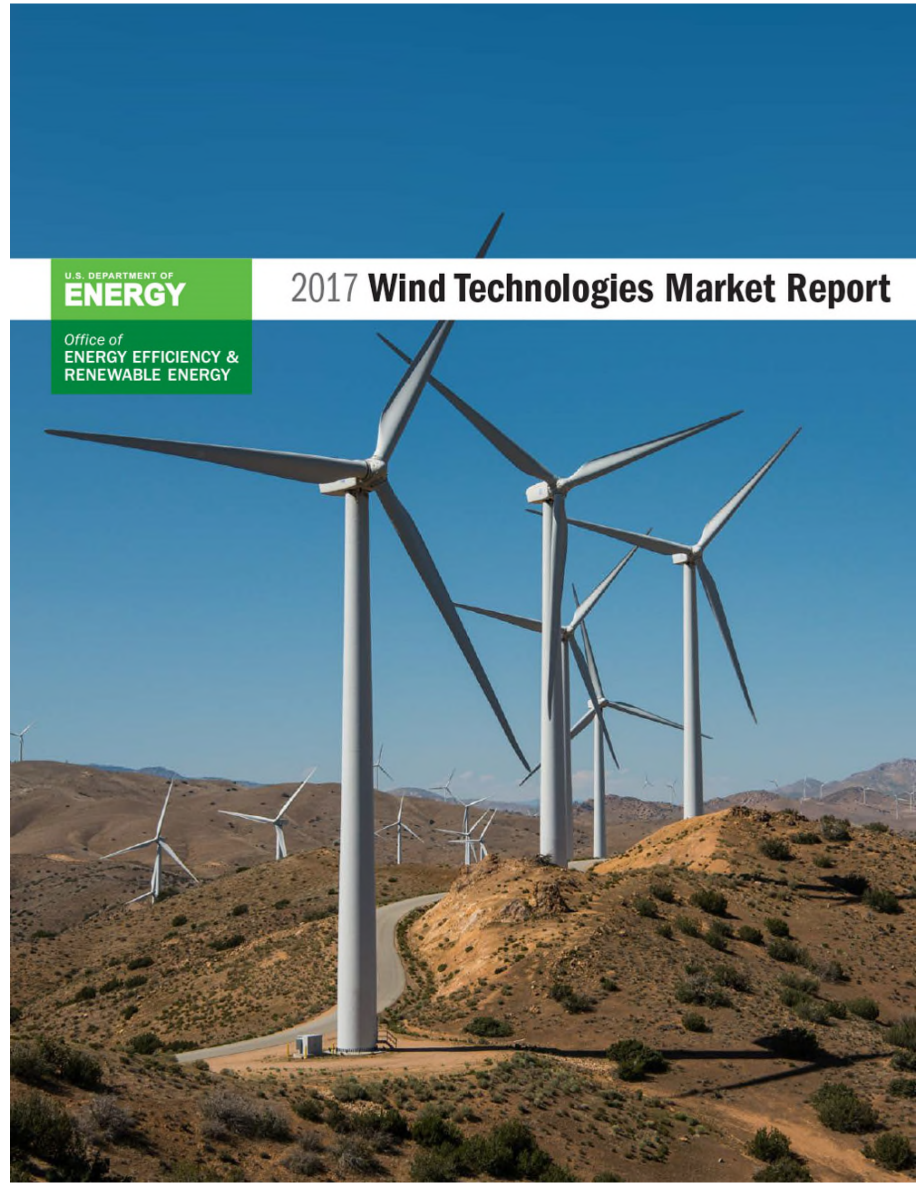
- Wind power price trends
- Policy & market drivers
- Future outlook

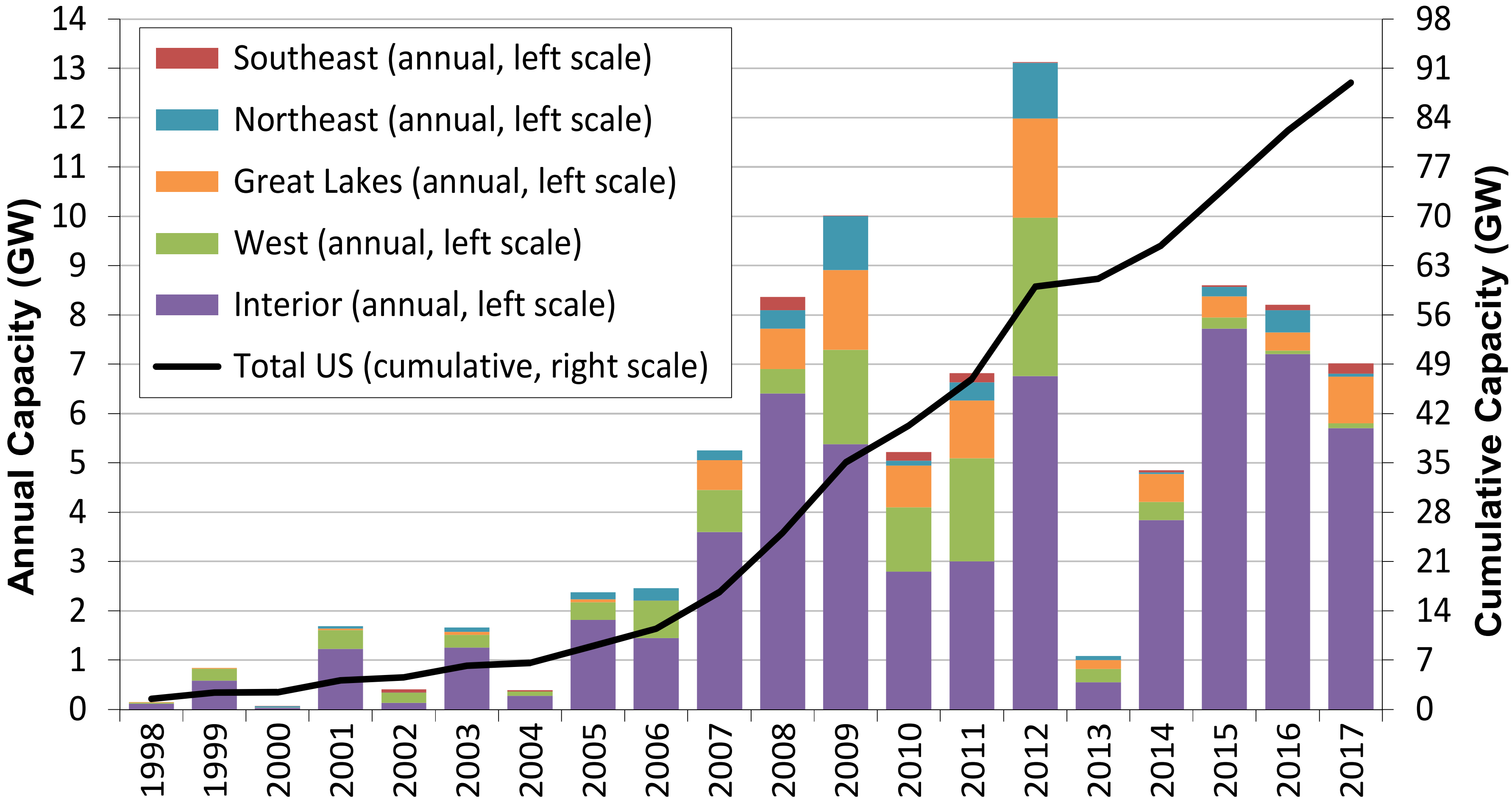


Key Findings

- Wind capacity additions continued at a rapid pace in 2017, with significant additional new builds anticipated over next three years in part due to PTC
- Wind has been a significant source of new electric generation capacity additions in the U.S. in recent years
- Supply chain is diverse and multifaceted, with strong domestic content for nacelle assembly, towers, and blades
- Turbine scaling is significantly boosting wind project performance, while the installed cost of wind projects has declined
- Wind power sales prices are at all-time lows, enabling economic competitiveness (with the PTC) despite low natural gas prices
- Growth beyond current PTC cycle remains uncertain: could be blunted by declining federal tax support, expectations for low natural gas prices and solar costs, and modest electricity demand growth

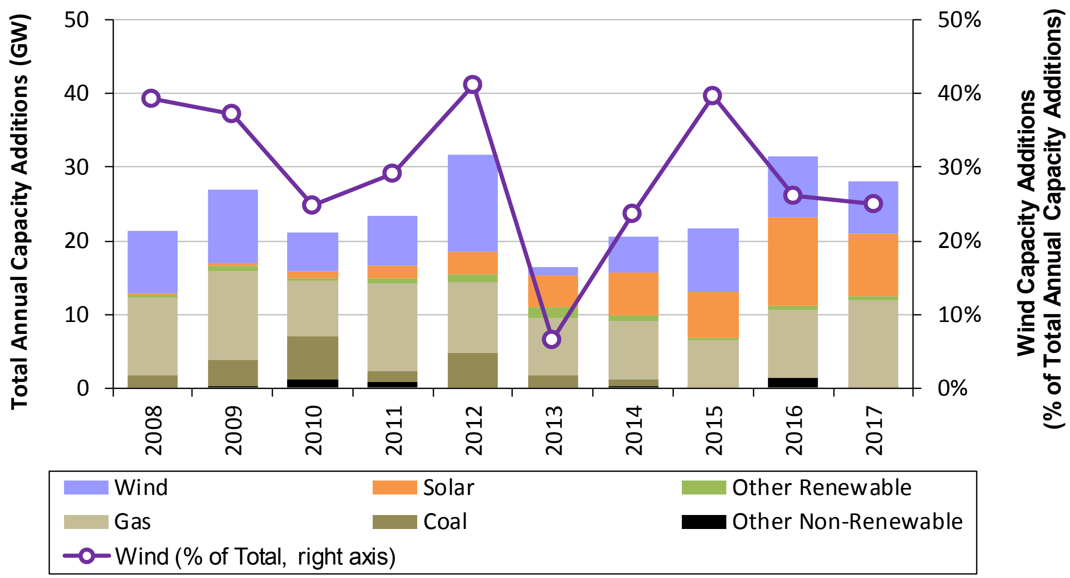
Installation Trends

Wind Power Additions Continued at a Rapid Pace in 2017, with 7,017 MW of New Capacity, Bringing the Total to 88,973 MW

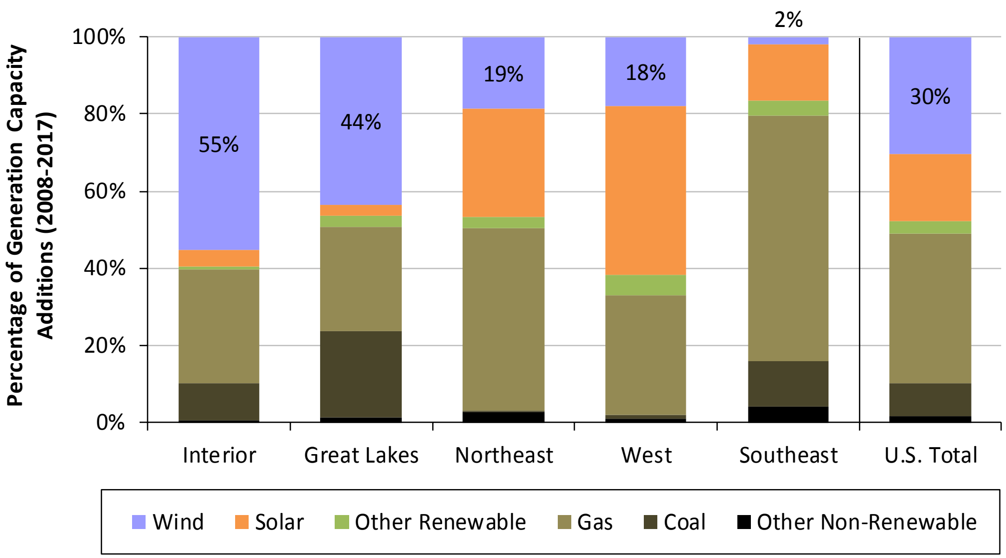


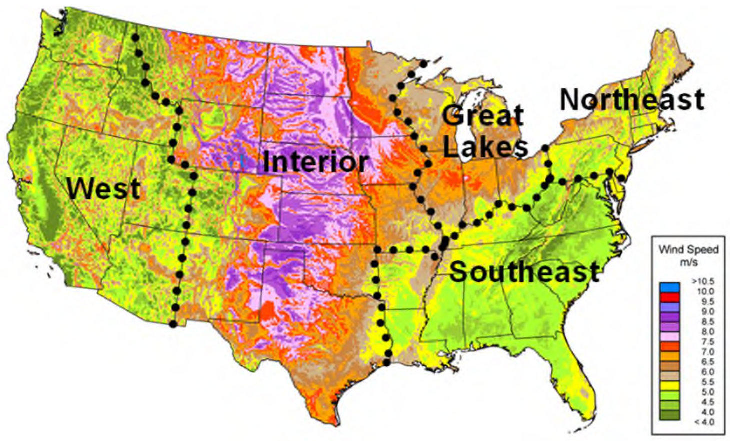
- $11 billion invested in wind power project additions in 2017
- Over 80% of new 2017 capacity located in the Interior region
- Partial repowering trend: 2,131 MW of existing plants retrofitted w/ longer blades

Wind Power Represented 25% of Electric-Generating Capacity Additions in 2017, Behind Solar and Natural Gas



Over the last decade, wind has comprised 30% of capacity additions nationwide, and a much higher proportion in some regions



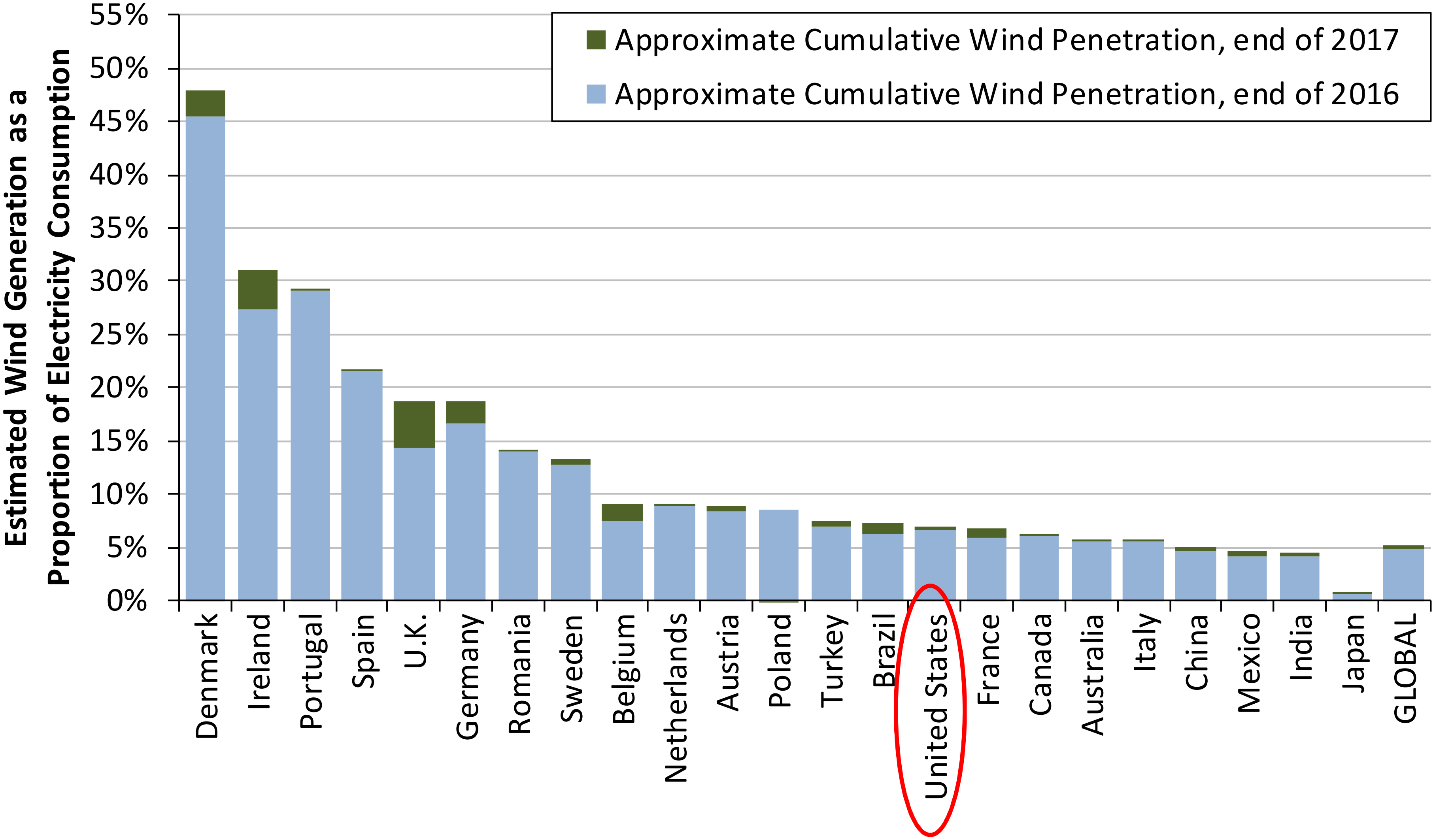


Globally, the U.S. Placed 2nd in Annual Wind Power Capacity Additions in 2017, and in Cumulative Wind Power Capacity

Annual Capacity (2017, MW)		Cumulative Capacity (end of 2017, MW)	
China	19,660	China	188,392
United States	**7,017**	**United States**	**88,973**
Germany	6,581	Germany	56,132
United Kingdom	4,270	India	32,848
India	4,148	Spain	23,170
Brazil	2,022	United Kingdom	18,872
France	1,694	France	13,759
Turkey	766	Brazil	12,763
South Africa	618	Canada	12,239
Finland	535	Italy	9,479
Rest of World	5,182	*Rest of World*	82,391
TOTAL	**52,492**	**TOTAL**	**539,019**

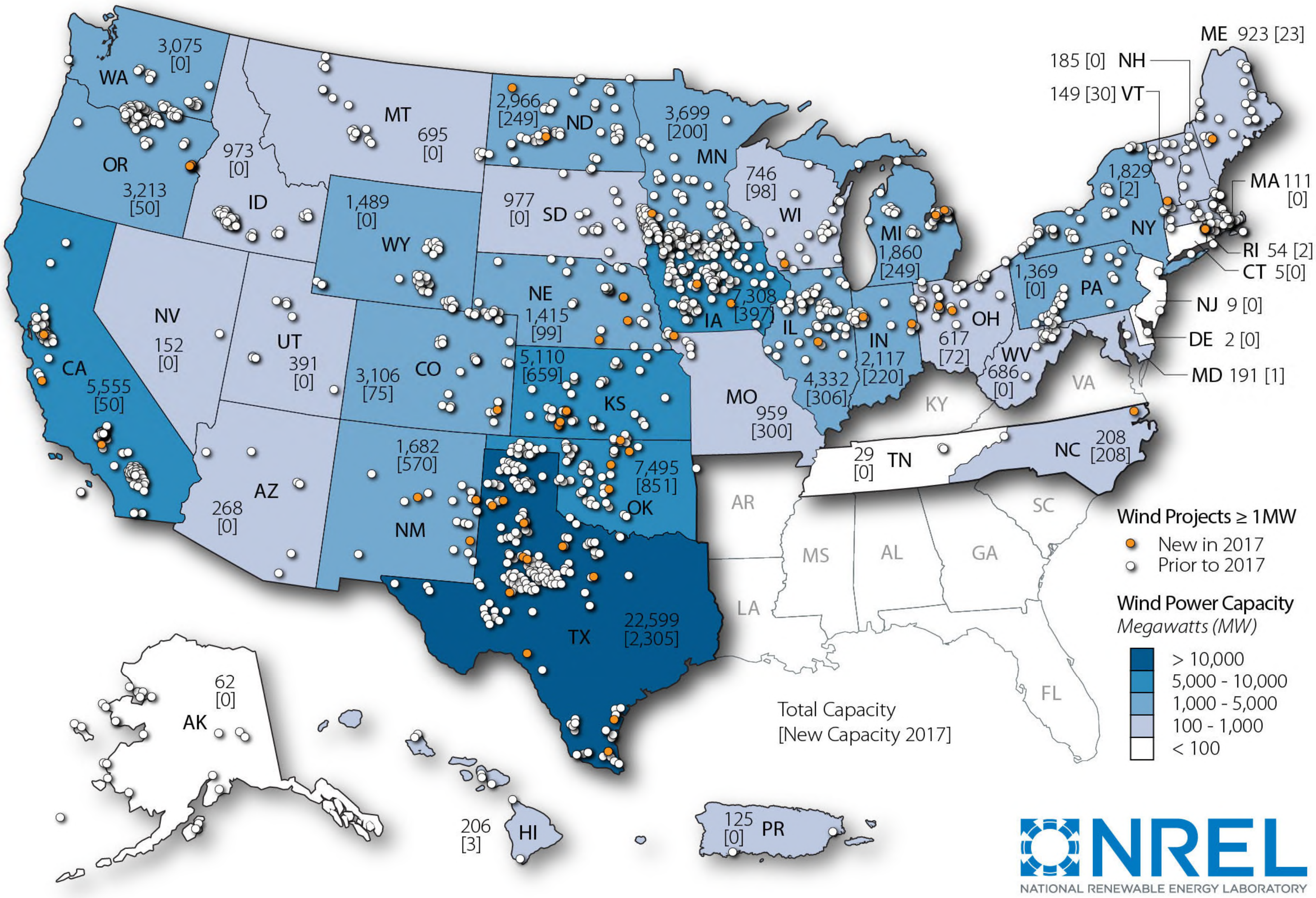
- **U.S. also remains a distant second to China in cumulative capacity**
- **Global wind additions in 2017 were below the 54,600 MW added in 2016 and the record level of 63,000 MW added in 2015**

The United States is Lagging Other Countries in Wind as a Percentage of Electricity Consumption



Note: Figure only includes the countries with the most installed wind power capacity at the end of 2017

The Geographic Spread of Wind Power Projects Across the United States Is Broad, with the Exception of the Southeast



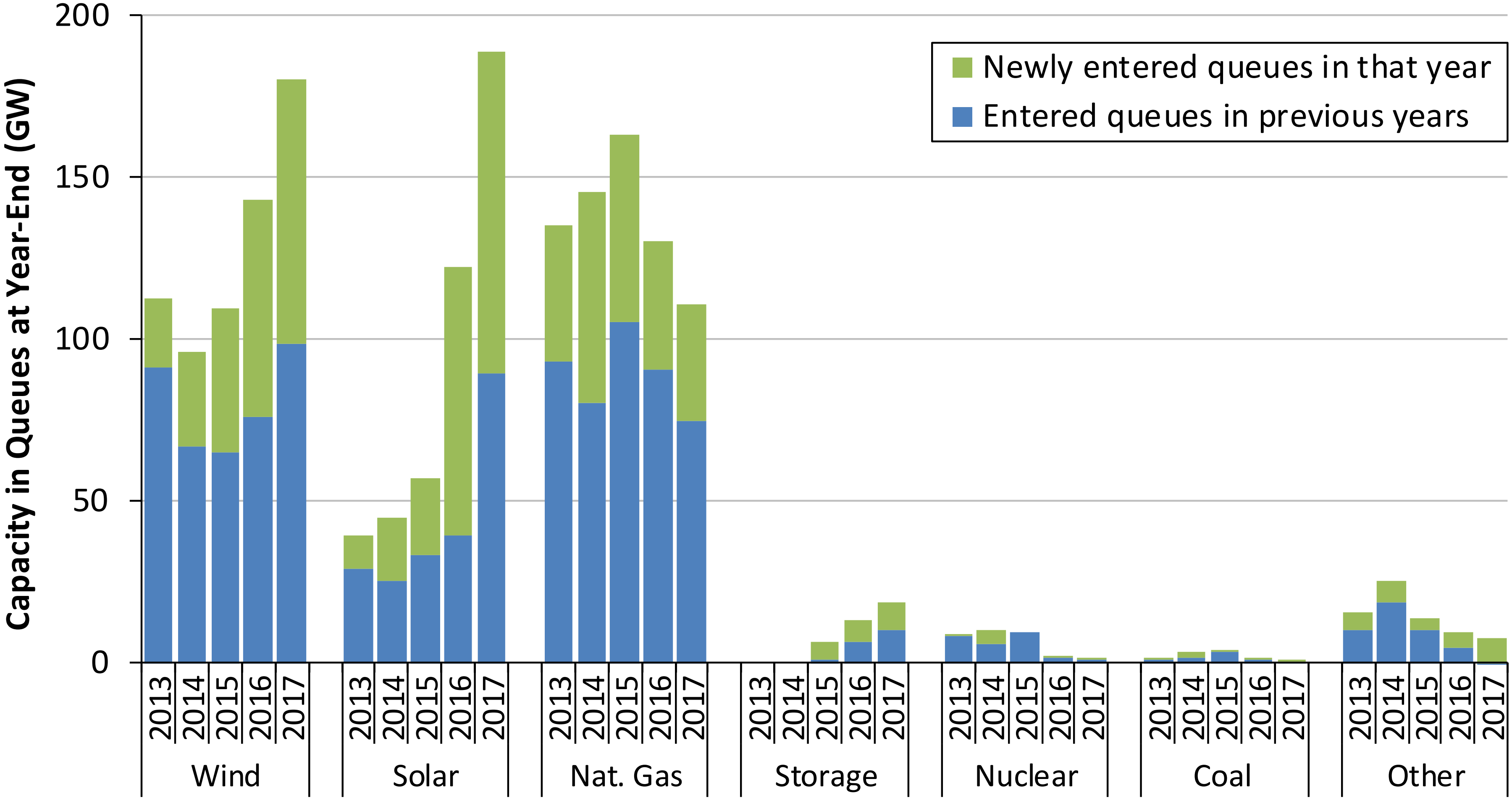
Note: Numbers within states represent cumulative installed wind capacity and, in brackets, annual additions in 2017

Texas Installed the Most Wind Power Capacity in 2017; 14 States Exceed 10% Wind Energy, 4 States Exceed 30%

Installed Capacity (MW)				2017 Wind Generation as a Percentage of:			
Annual (2017)		Cumulative (end of 2017)		In-State Generation		In-State Load	
Texas	2,305	Texas	22,599	Iowa	36.9%	North Dakota	58.3%
Oklahoma	851	Oklahoma	7,495	Kansas	36.0%	Kansas	47.1%
Kansas	659	Iowa	7,308	Oklahoma	31.9%	Iowa	43.0%
New Mexico	570	California	5,555	South Dakota	30.1%	Oklahoma	40.9%
Iowa	397	Kansas	5,110	North Dakota	26.8%	Wyoming	26.3%
Illinois	306	Illinois	4,332	Maine	19.9%	South Dakota	25.7%
Missouri	300	Minnesota	3,699	Minnesota	18.2%	New Mexico	19.7%
North Dakota	249	Oregon	3,213	Colorado	17.6%	Maine	19.5%
Michigan	249	Colorado	3,106	Idaho	15.4%	Colorado	17.5%
Indiana	220	Washington	3,075	Texas	14.8%	Nebraska	17.4%
North Carolina	208	North Dakota	2,996	Nebraska	14.6%	Texas	17.3%
Minnesota	200	Indiana	2,117	New Mexico	13.5%	Minnesota	16.7%
Nebraska	99	Michigan	1,860	Vermont	13.4%	Montana	14.8%
Wisconsin	98	New York	1,829	Oregon	11.1%	Oregon	13.5%
Colorado	75	New Mexico	1,682	Wyoming	9.4%	Idaho	10.4%
Ohio	72	Wyoming	1,489	Montana	7.6%	Illinois	8.3%
Oregon	50	Nebraska	1,415	California	6.8%	Washington	8.3%
California	50	Pennsylvania	1,369	Hawaii	6.5%	Hawaii	6.9%
Vermont	30	South Dakota	977	Washington	6.5%	California	5.5%
Maine	23	Idaho	973	Illinois	6.2%	Vermont	5.2%
Rest of U.S.	7	*Rest of U.S.*	6,774	*Rest of U.S.*	1.1%	*Rest of U.S.*	1.2%
TOTAL	7,017	TOTAL	88,973	TOTAL	6.3%	TOTAL	6.9%

- **2017 Wind Penetration by ISO:** SPP: 23.2%; ERCOT: 17.4%; MISO: 7.7%; CAISO: 6.0%; NYISO: 2.7%; PJM: 2.7%; ISO-NE: 2.6%

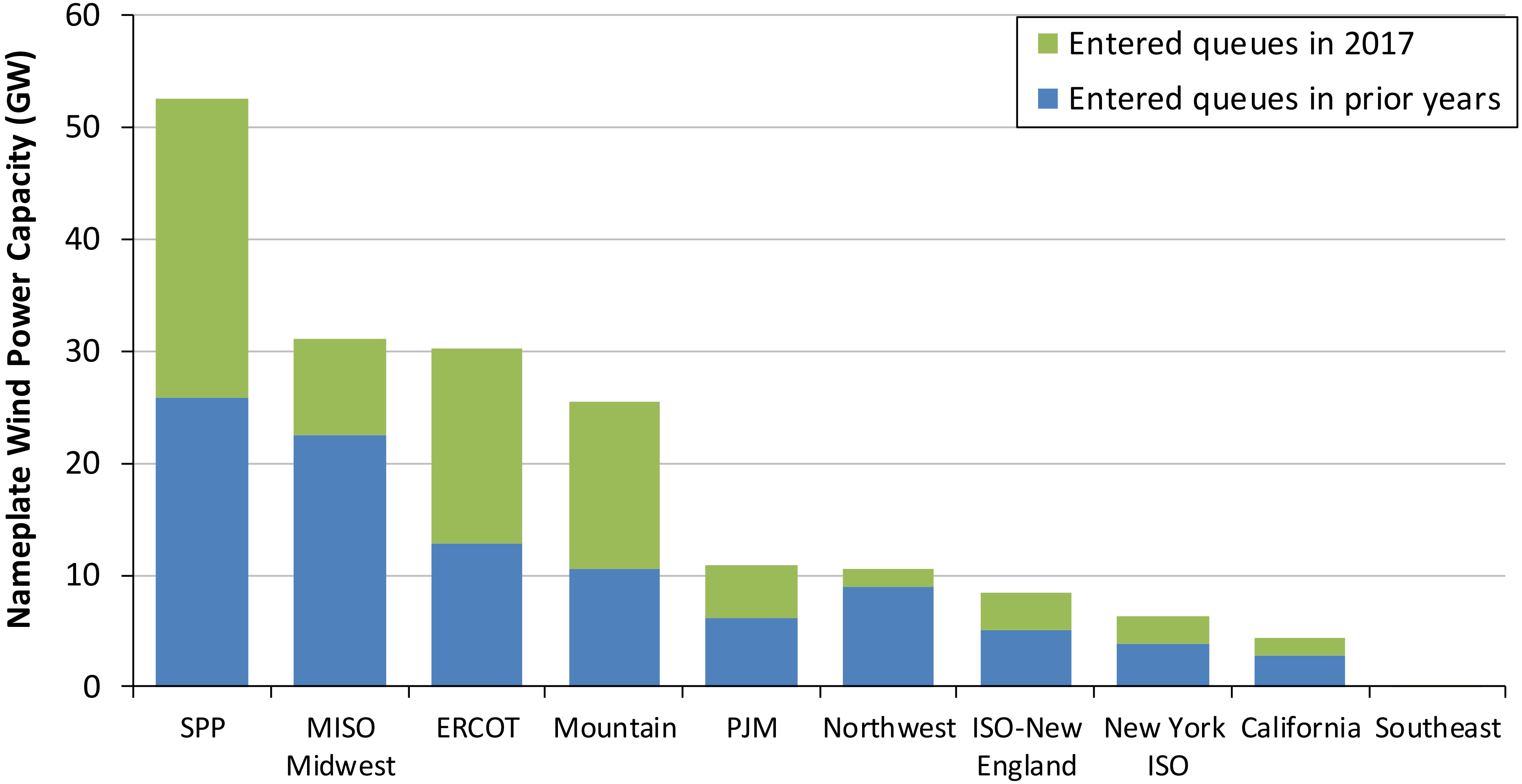
A Record Level of Wind Power Capacity Entered Transmission Interconnection Queues in 2017; Solar and Storage Also Growing



- **AWEA reports 33 GW of capacity under construction or in advanced development at end of 1Q2018**

Note: Not all of this capacity will be built

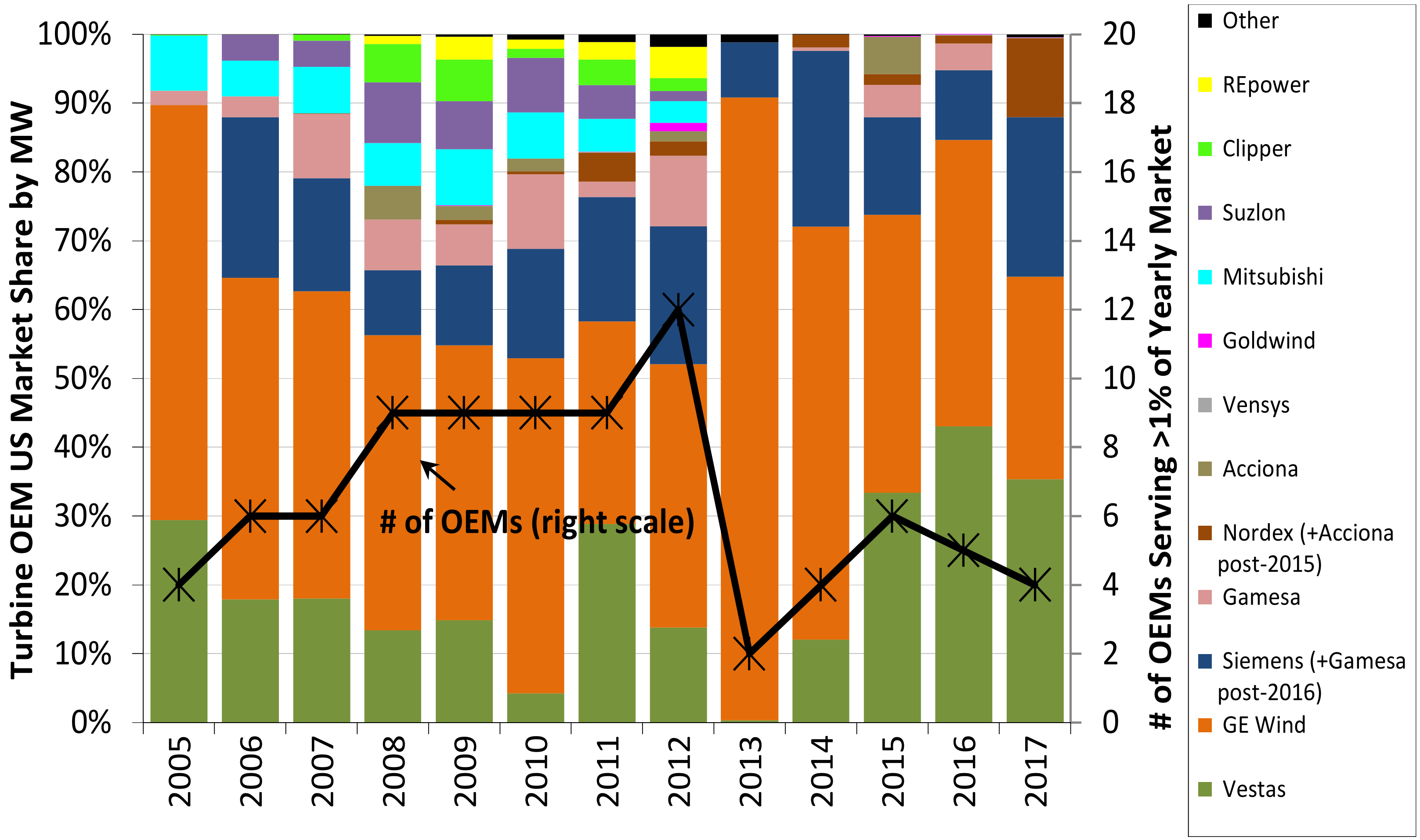
Larger Amounts of Wind Power Capacity Planned for Southwest Power Pool, Midwest, Texas, and Mountain Regions



Note: Not all of this capacity will be built

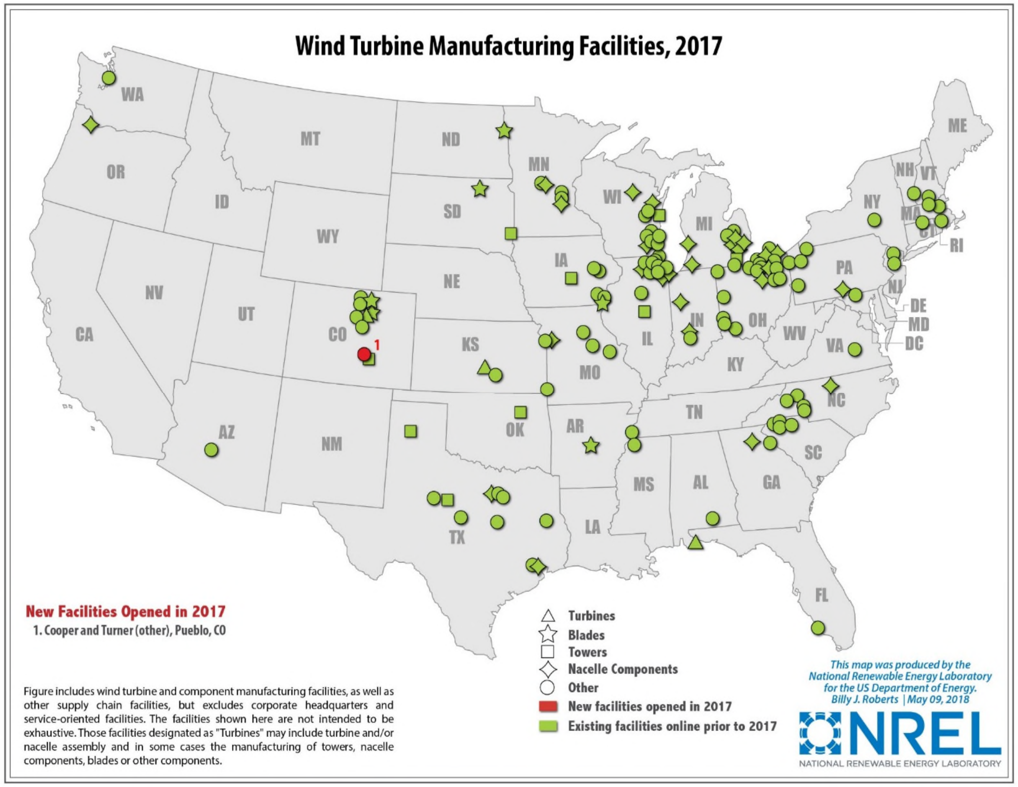
Industry Trends

Vestas, GE and Siemens-Gamesa Captured 88% of the U.S. Market in 2017



- Globally, Vestas, Siemens Gamesa, Goldwind and GE were the top suppliers of wind turbines for land-based applications
- Chinese suppliers occupied 4 of the top 10 spots in the global ranking, based primarily on sales within their domestic market

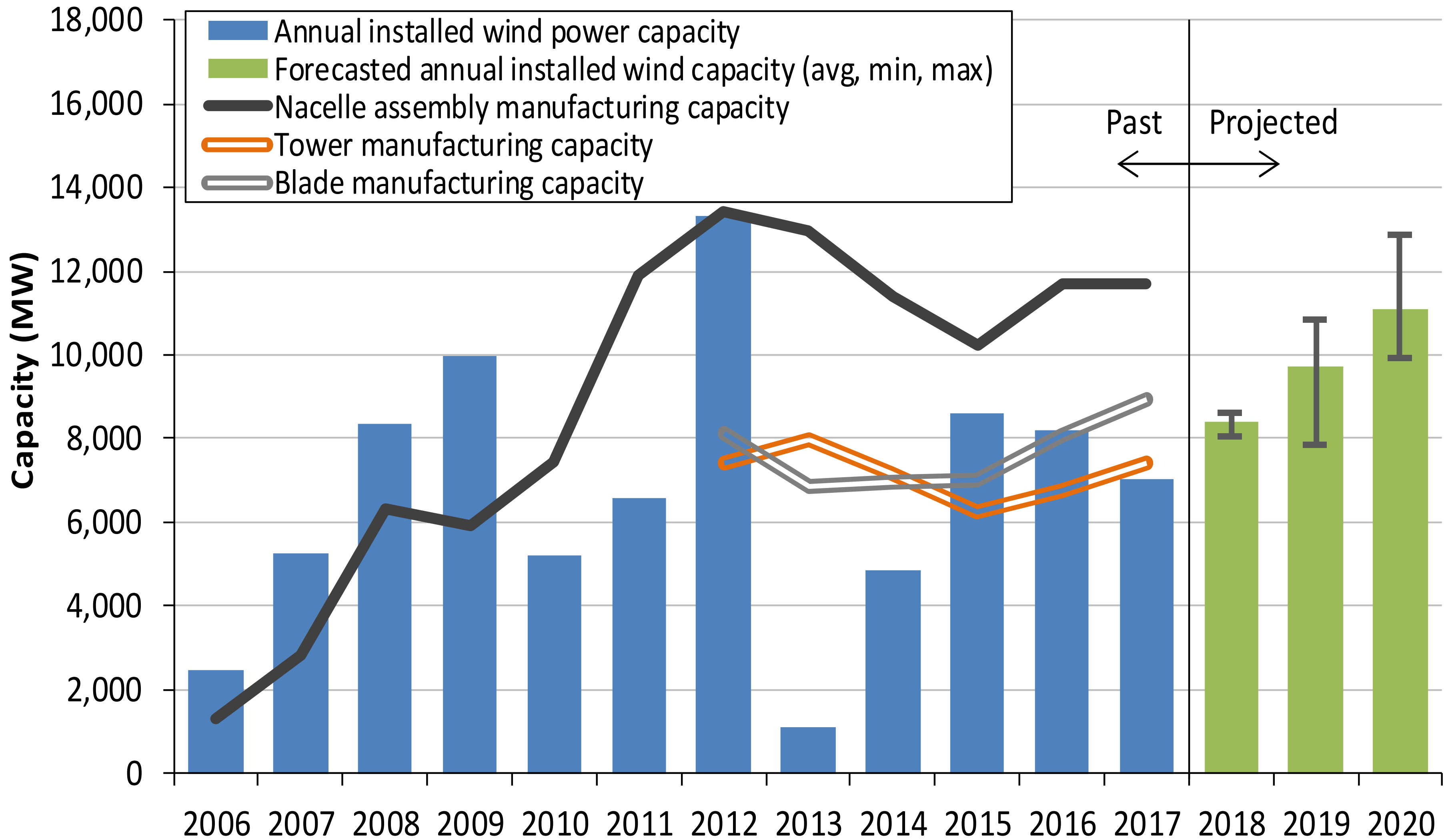
The Domestic Supply Chain for Wind Equipment is Diverse



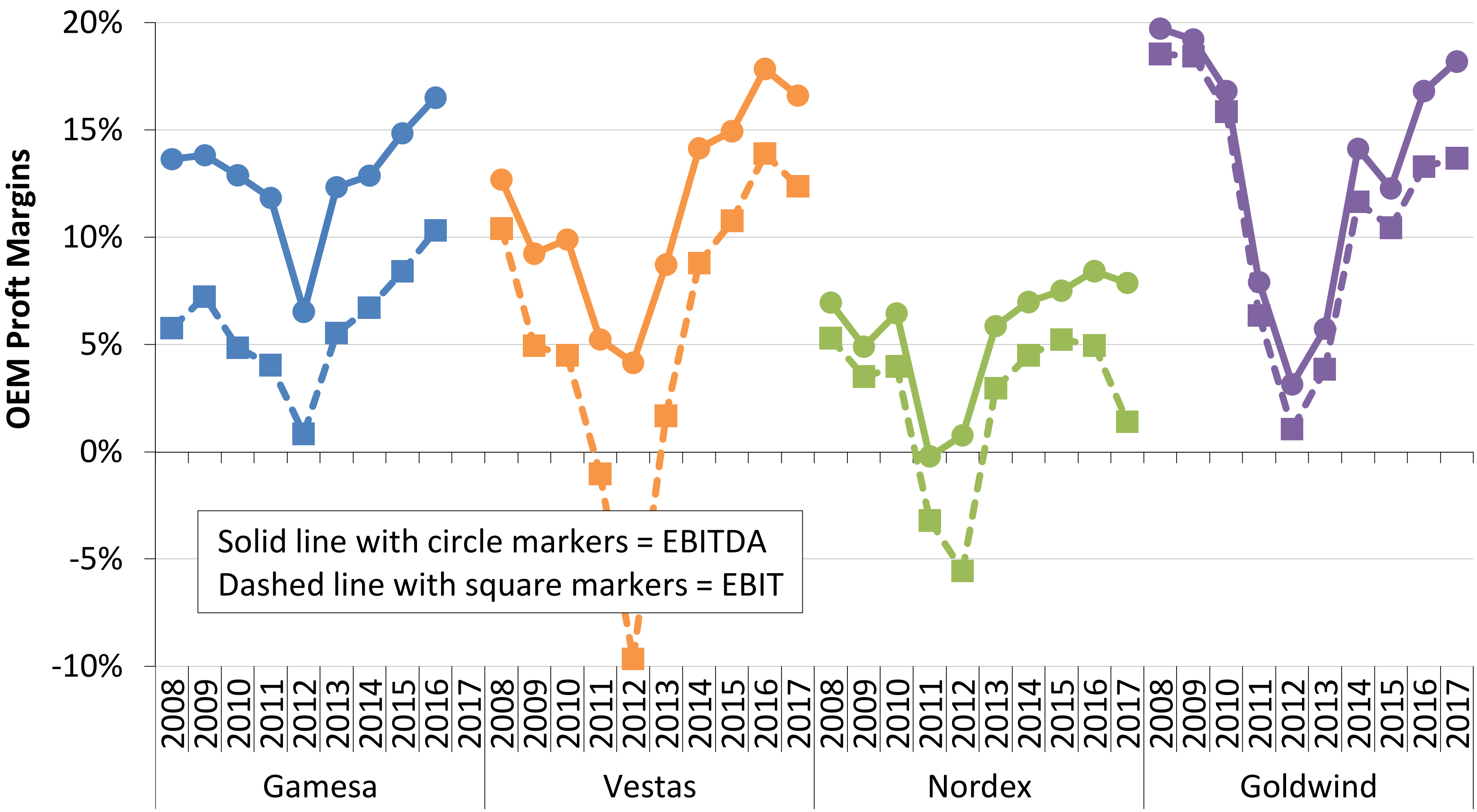
Note: map not intended to be exhaustive

- Some manufacturers increased the size of their U.S. workforce in 2017 and/or expanded existing facilities, but expectations for significant long-term supply-chain expansion has become less optimistic
- Continued near-term expected growth, but strong competitive pressures and expected reduced demand as PTC is phased out
- At least three domestic manufacturing facility closures in 2017; one opening
- Many manufacturers remain; three largest OEMs serving U.S. market all have at least one U.S. facility
- Wind-related jobs reached a new all-time high, at 105,500

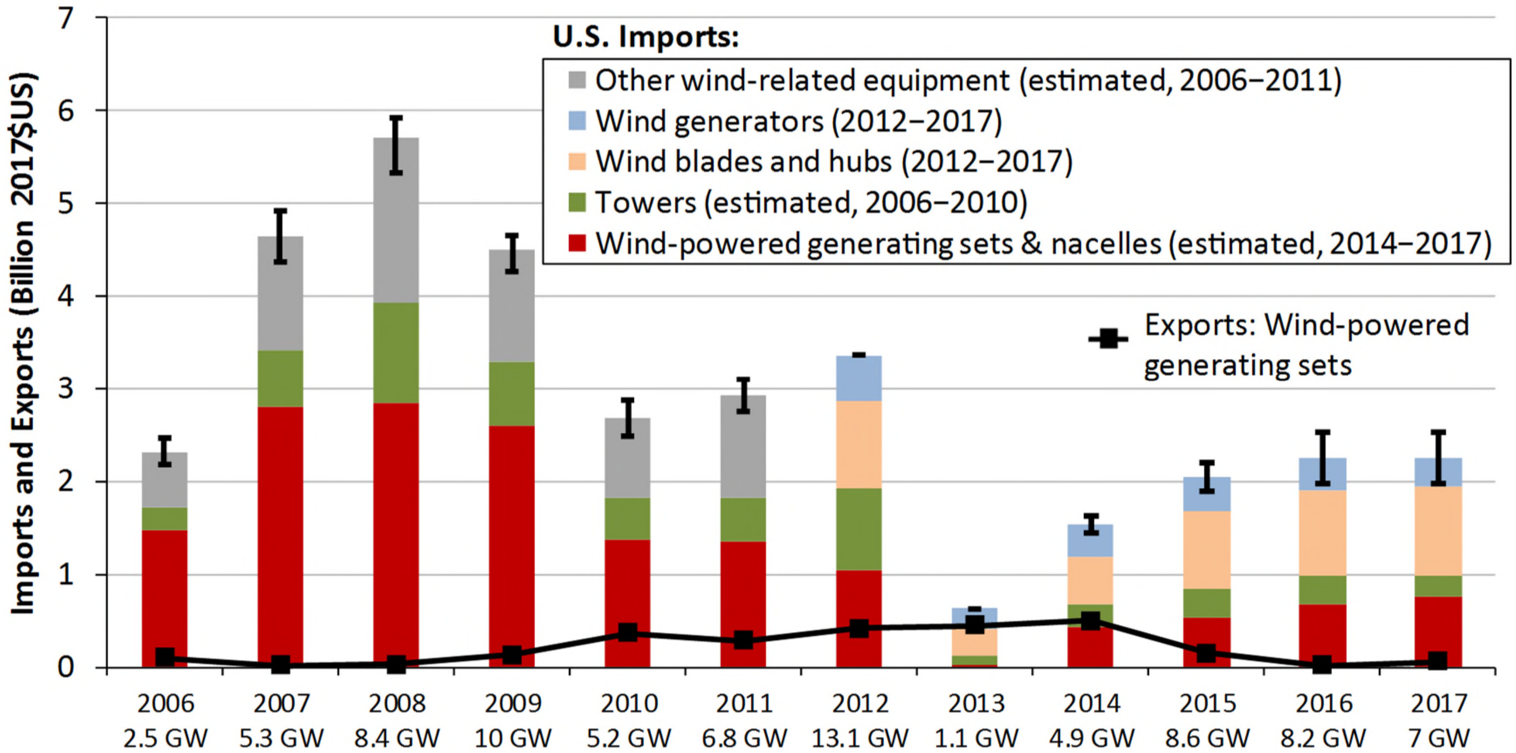
Domestic Manufacturing Capability for Nacelle Assembly, Towers, & Blades Reasonably Well Balanced Against Historical Demand



Turbine OEM Profitability Has Generally Been Strong in Recent Years, Compared to Near Breakeven from 2011 through 2013



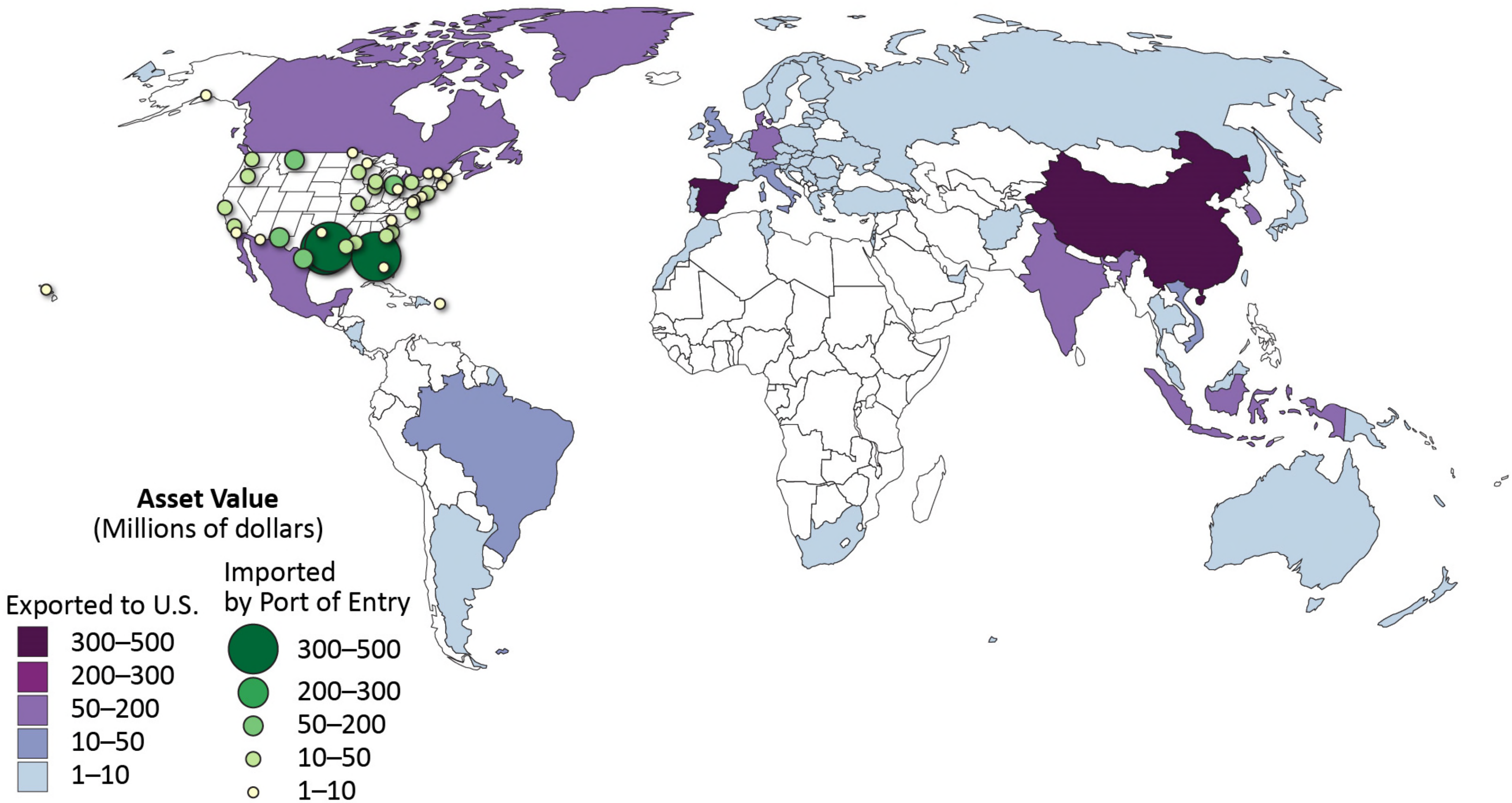
Imports of Wind Equipment into the United States Are Sizable; Exports Remained Low in 2017



Notes: Figure only includes tracked trade categories; misses other wind-related imports; see full report for the assumptions used to generate this figure

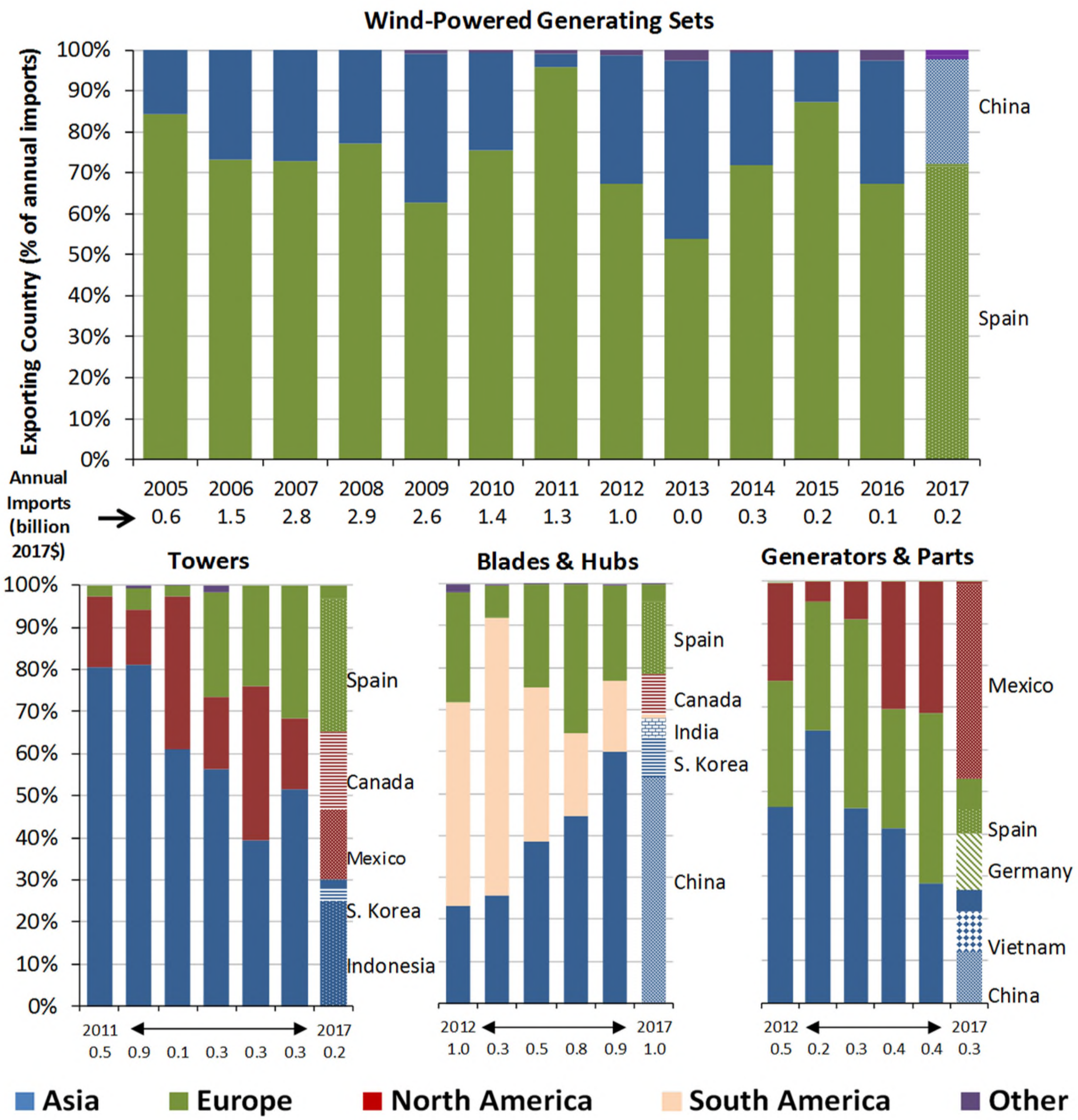
- **U.S. is net importer of wind equipment**
- **Exports of wind-powered generating sets = $60 million in 2017**
- **No ability to track other wind-specific exports, but total 'tower and lattice mast' exports equaled $39 million**

Tracked Wind Equipment Imports in 2017: 50% from Asia, 36% from Europe, 14% from the Americas



Note: Tracked wind-specific equipment includes: wind-powered generating sets, towers, hubs and blades, wind generators and parts

Source Markets for Imports Have Varied Over Time, and By Type of Wind Equipment



- Majority of imports of wind-powered generating sets historically from home countries of OEMs, dominated by Europe
- Decline in imports of towers from Asia over time, in part due to tariff measures
- Majority of imports of blades & hubs from China
- Globally diverse sourcing strategy for generators & parts, but with drop from China & growth from Mexico

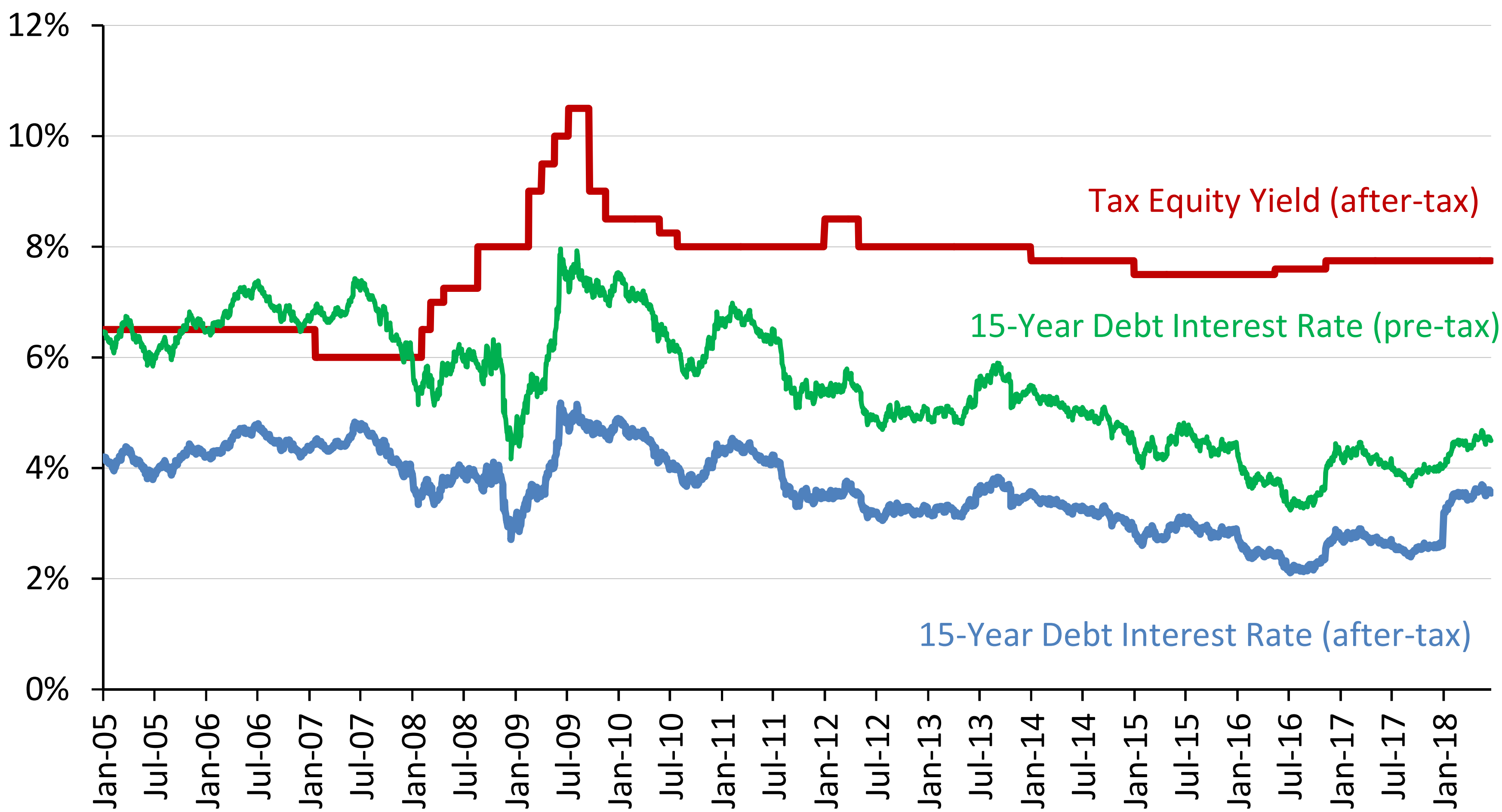
Domestic Manufacturing Content is Strong for Nacelle Assembly, Towers, and Blades, but not Equipment Internal to the Nacelle

Domestic Content for 2017 Turbine Installations in the United States:

Towers	Blades & Hubs	Nacelle Assembly
70–90%	50–70%	> 85%

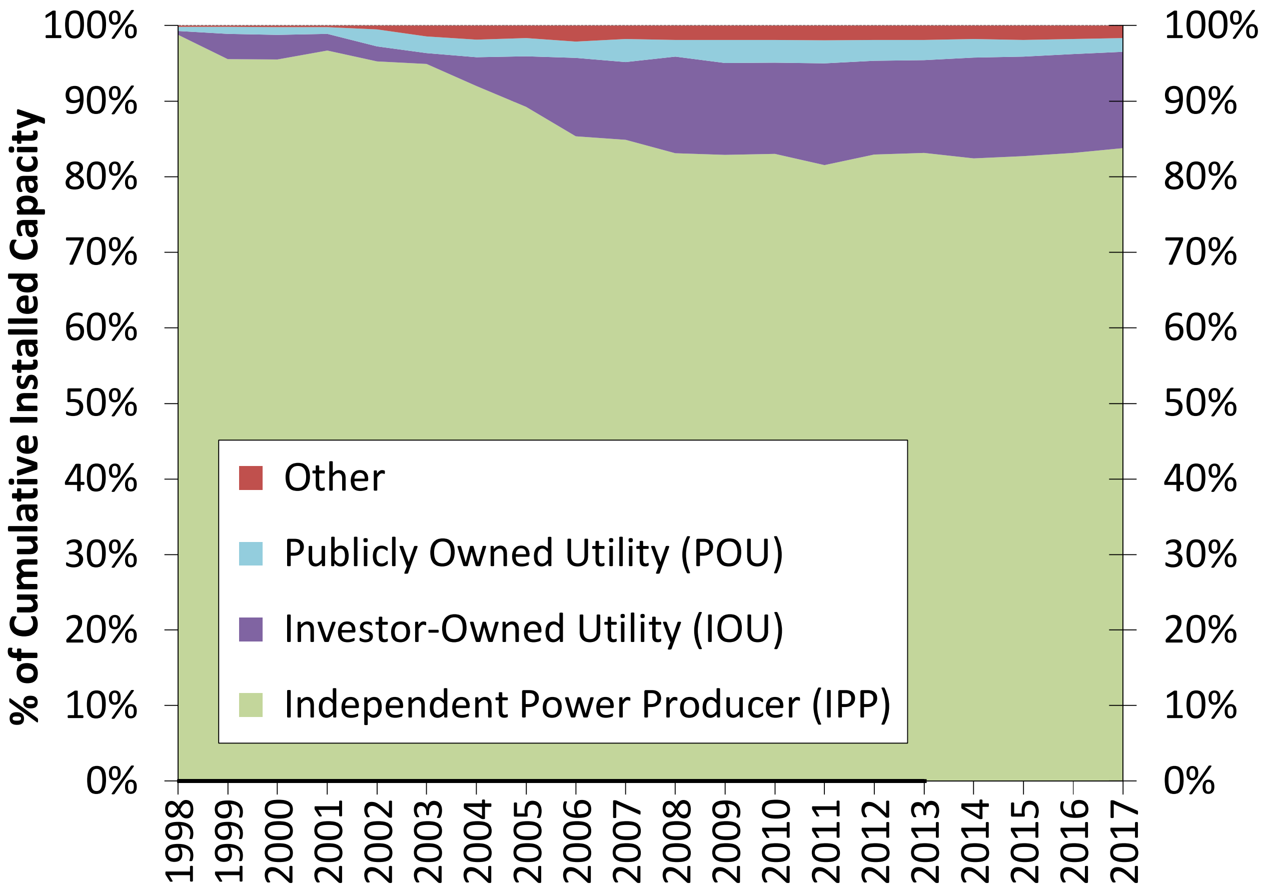
- **Imports occur in untracked trade categories, including many nacelle internals; nacelle internals generally have domestic content of < 20%**

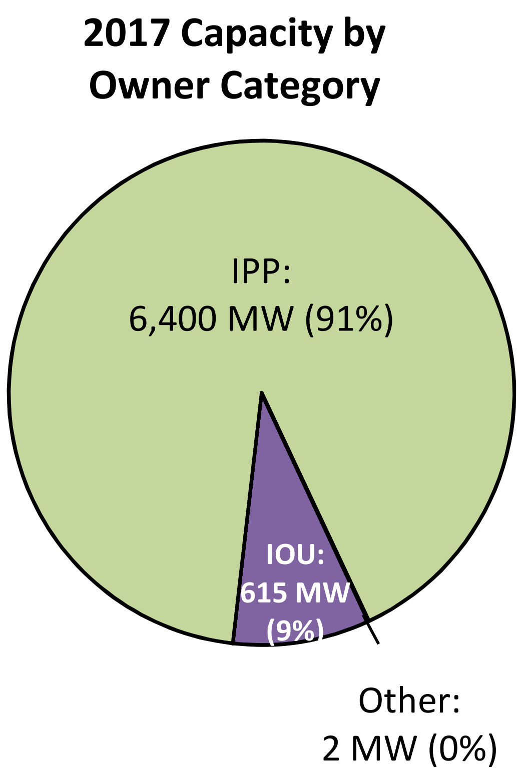
The Project Finance Environment Remained Strong in 2017



- Sponsors raised $6 billion of tax equity and $2.5 billion of debt in 2017
- Tax reform legislation contained a number of provisions with implications for wind finance, but general consensus that the overall impact will be benign

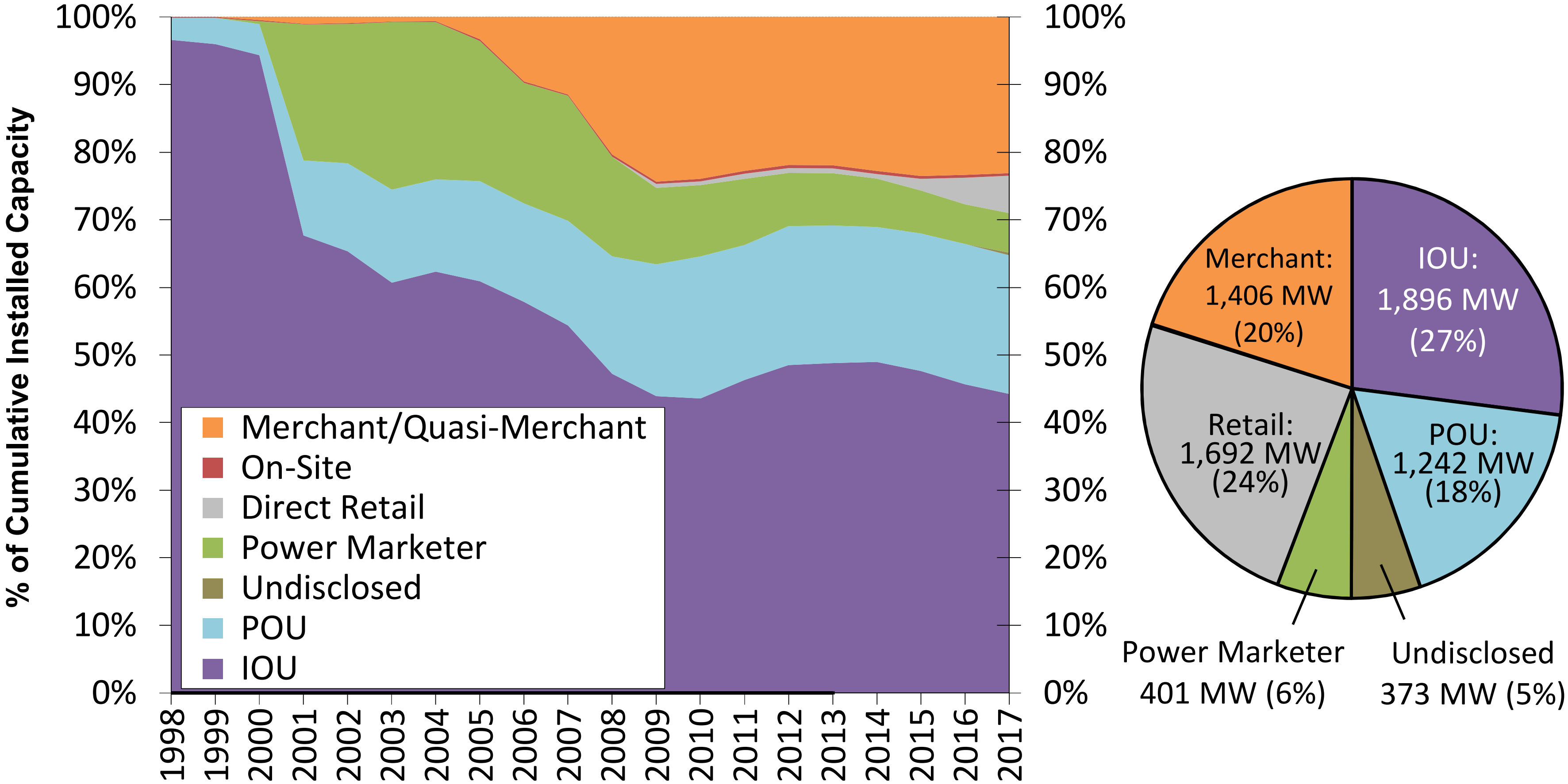
Independent Power Producers Own the Majority of Wind Assets Built in 2017





- **Utility ownership should increase in the coming years as many utilities have recently announced plans to build and own new wind assets.**

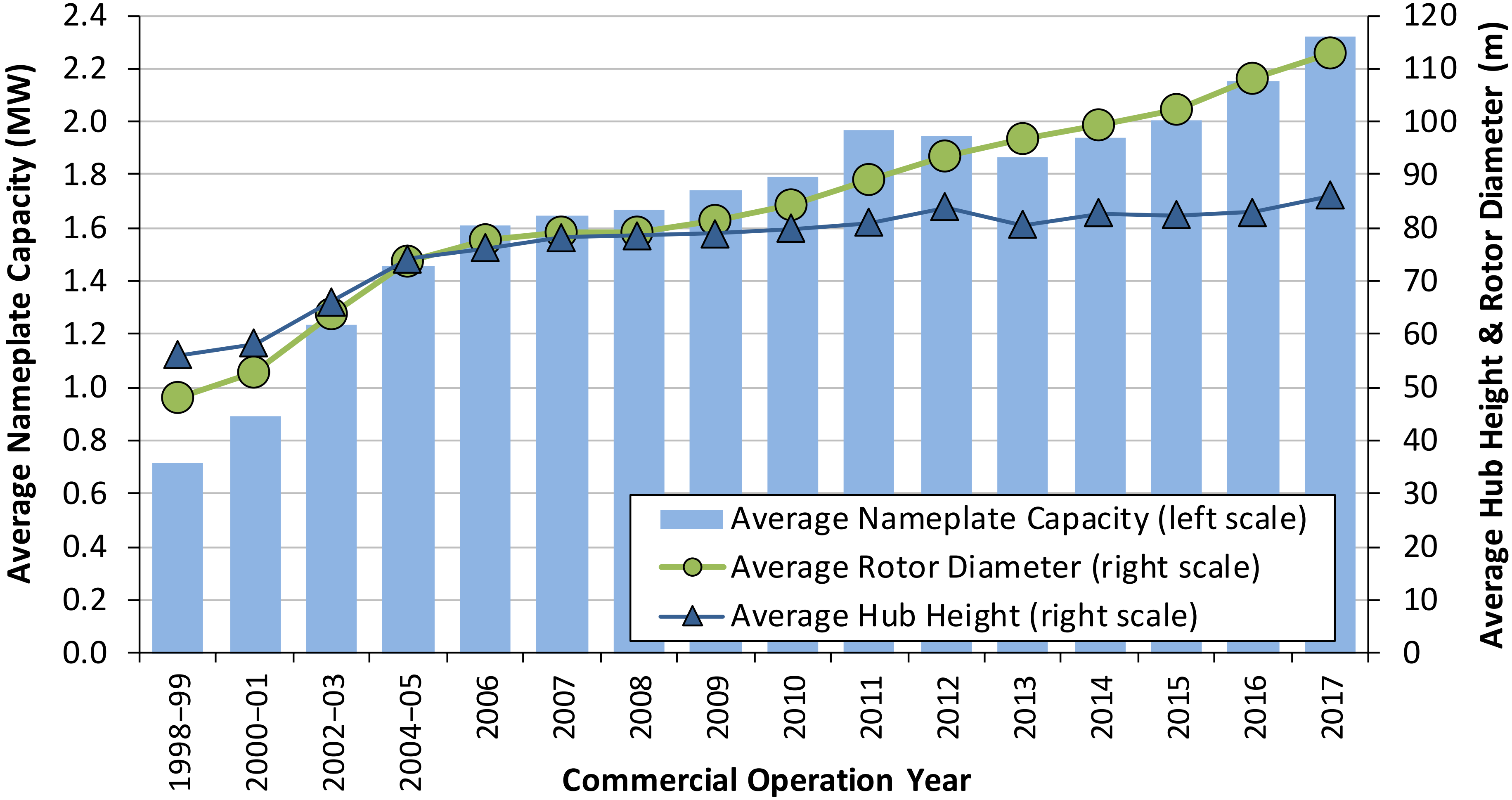
Long-Term Sales to Utilities Remained Most Common Off-Take, but Direct Retail Sales and Merchant Were Significant



- **24% of added wind capacity in 2017 are from direct retail sales; 40% of total wind capacity contracted through PPAs in 2017 involve non-utility buyers**

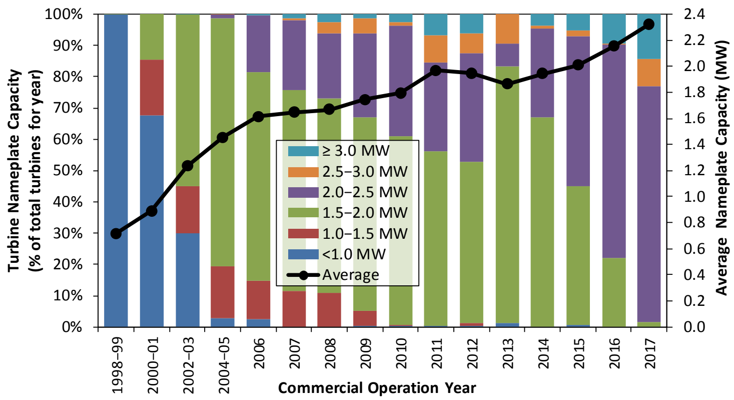
Technology Trends

Turbine Capacity, Rotor Diameter, and Hub Height Have All Increased Significantly Over the Long Term, and in 2017

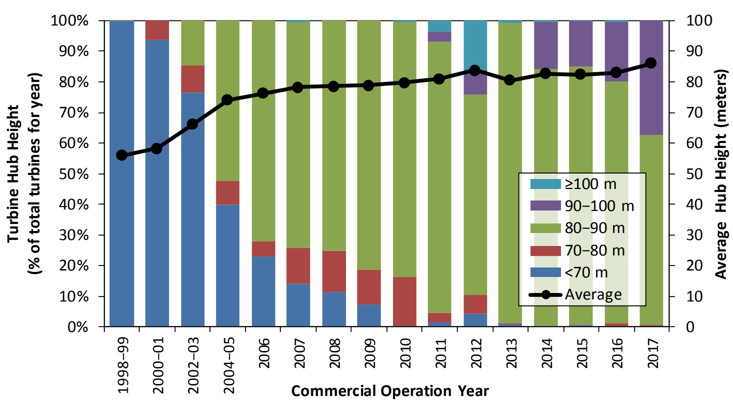


Growth in Rotor Diameter and Nameplate Capacity Have Outpaced Growth in Hub Height over the Last Two Decades

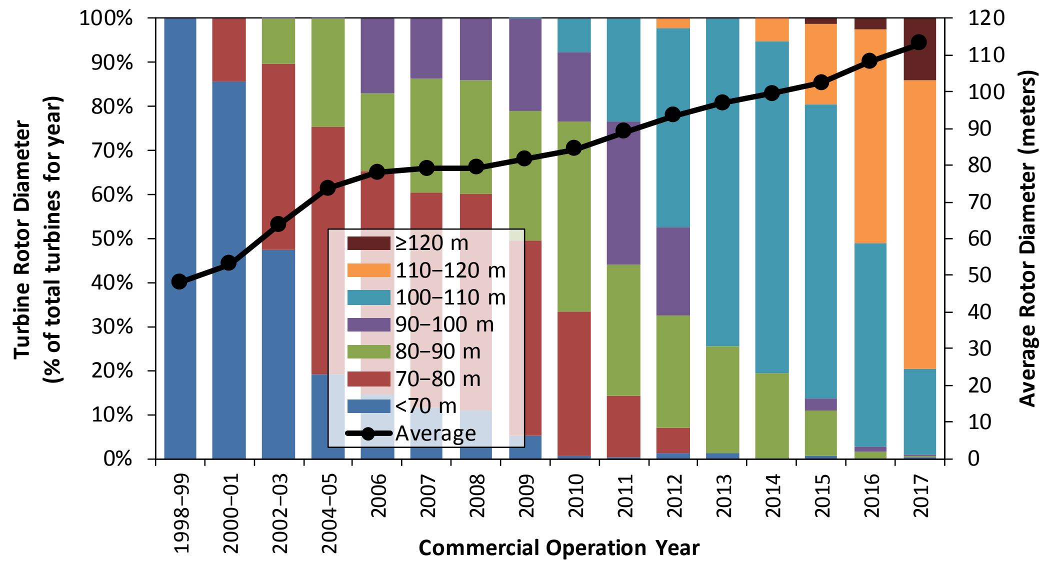
Nameplate Capacity



Hub Height

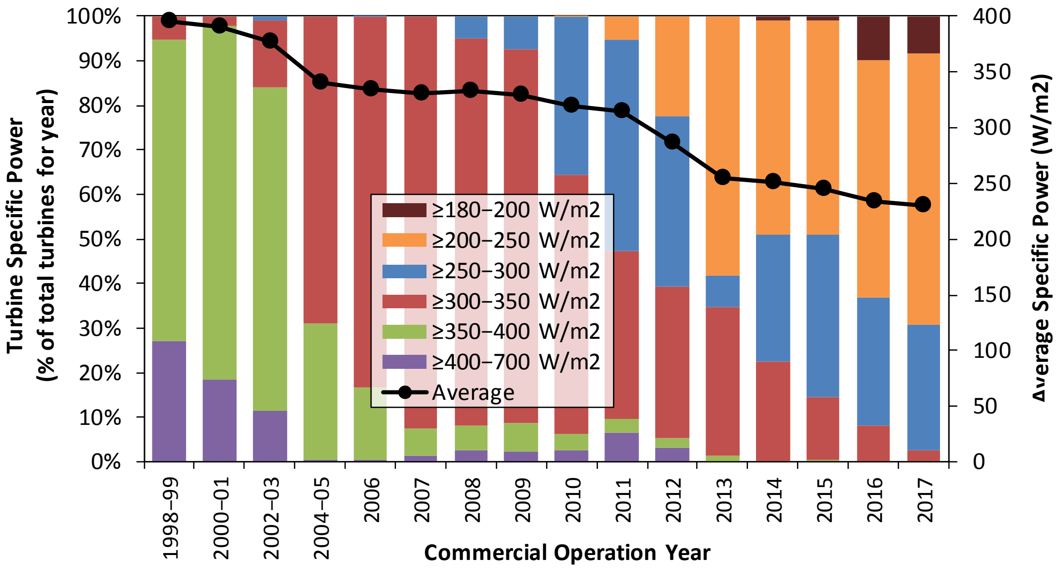


Rotor Diameter

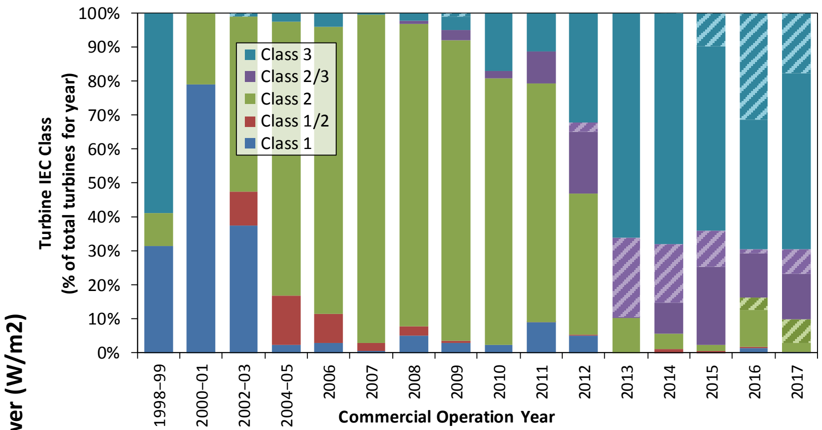


Turbines Originally Designed for Lower Wind Speed Sites Have Rapidly Gained Market Share

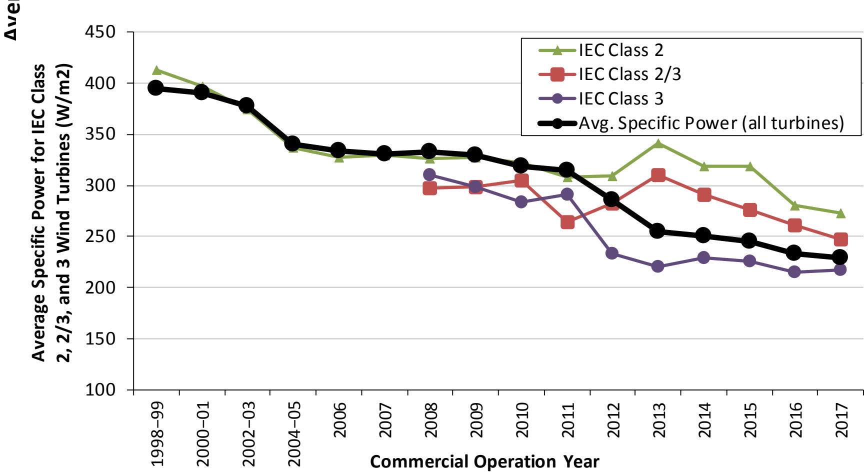
Specific Power



IEC Class

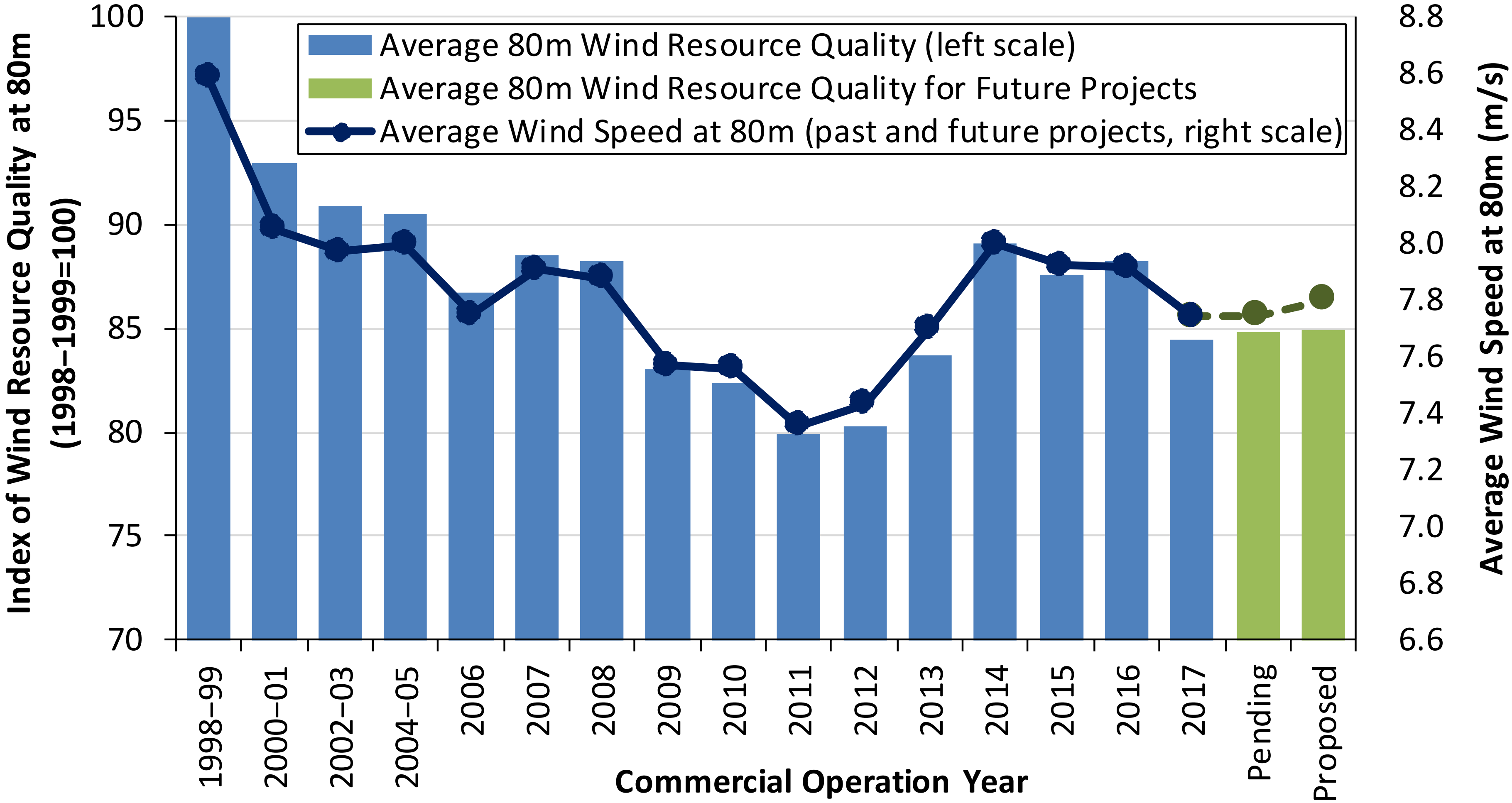


Specific Power by Selected IEC Class



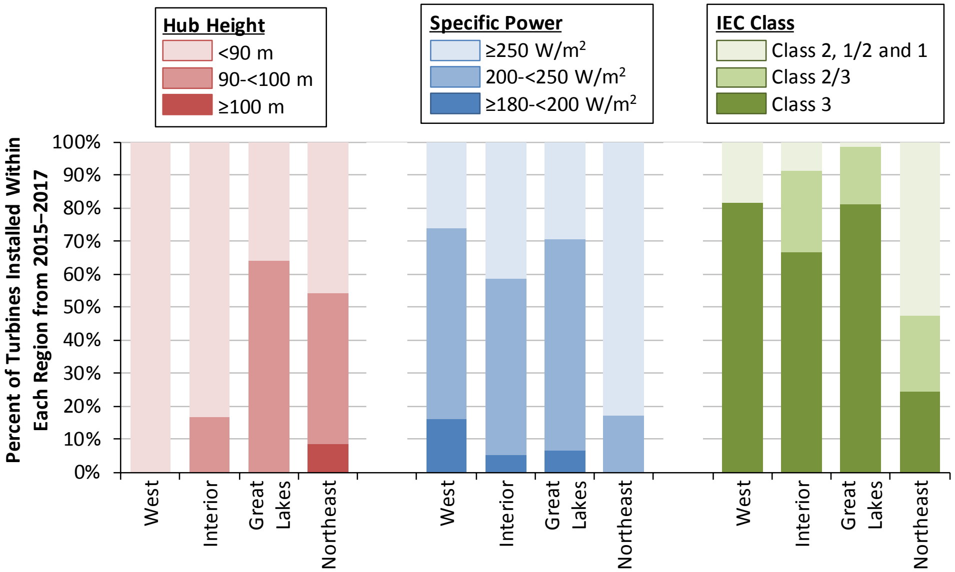
- **Specific power:** turbine nameplate capacity divided by swept rotor area; lower specific power leads to higher capacity factors, as shown later
- **IEC Class 1/2/3** represent turbines designed originally for high, medium, and low wind speed, respectively

Wind Turbines Were Deployed in Somewhat Lower Wind-Speed Sites in 2017 in Comparison to the Previous Three Years

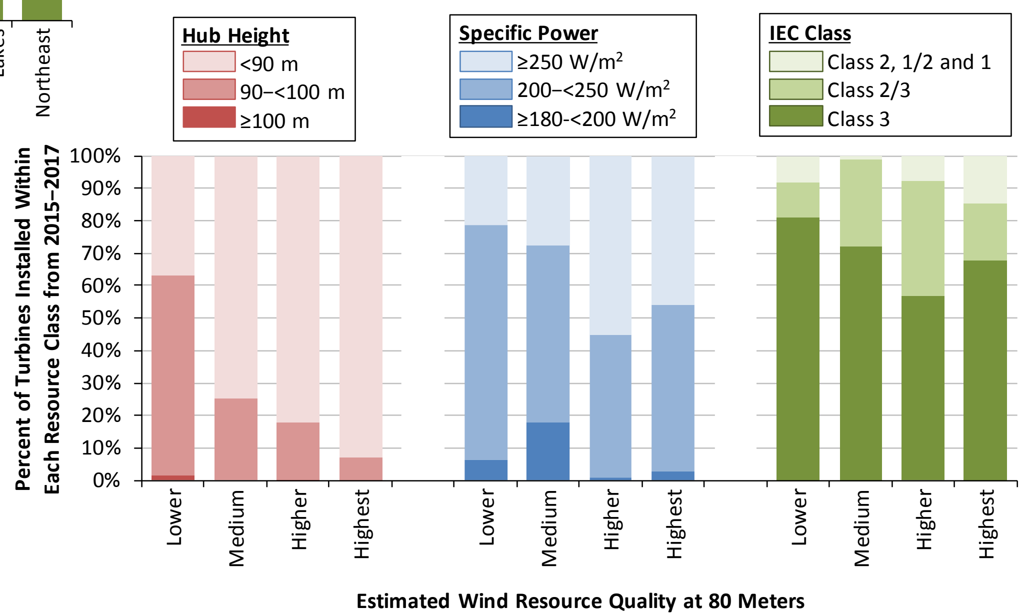


Low Specific Power Turbines Are Deployed in Low & High Wind Speeds; Taller Towers Predominate in Great Lakes & Northeast

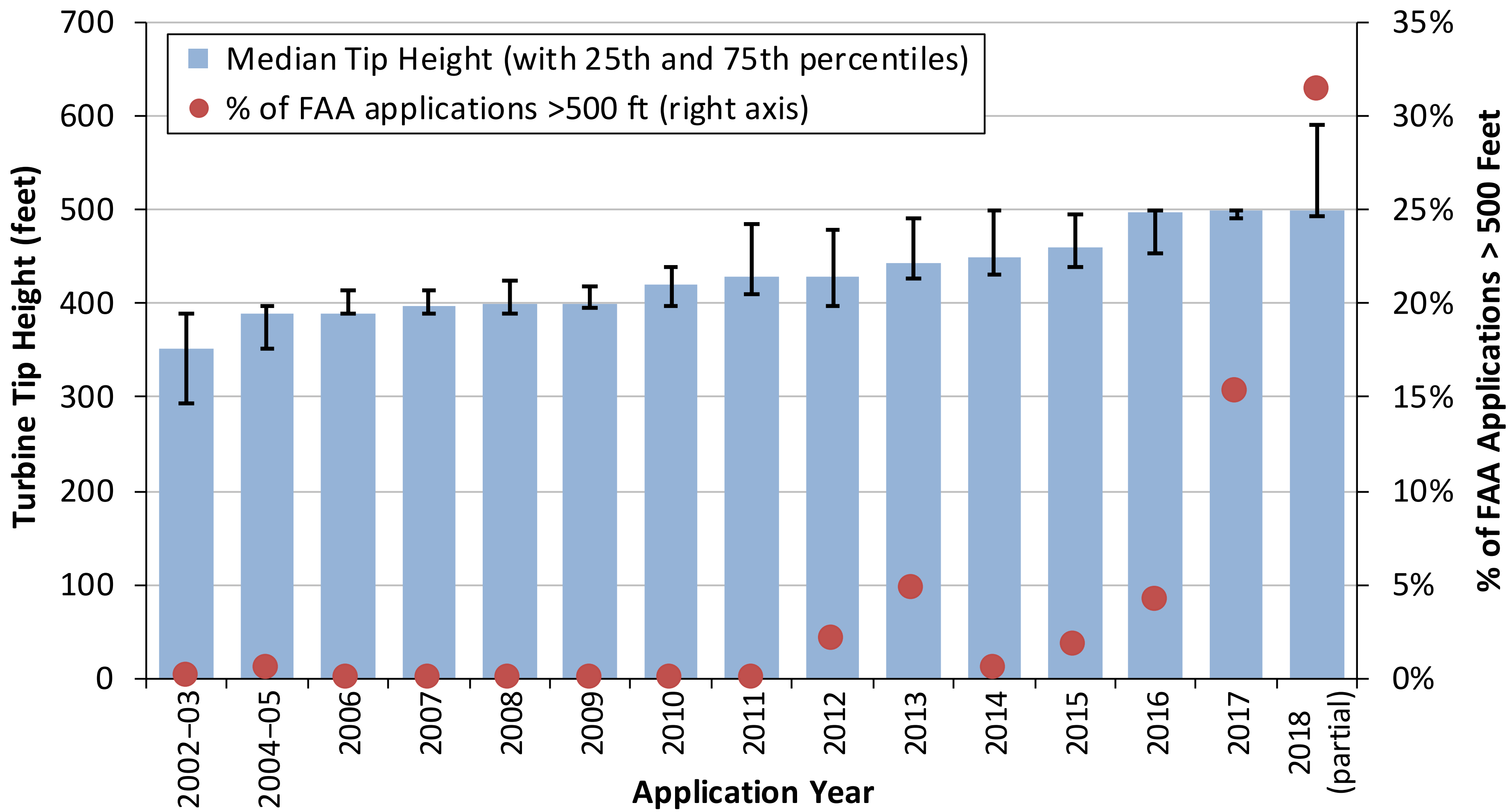
By Region



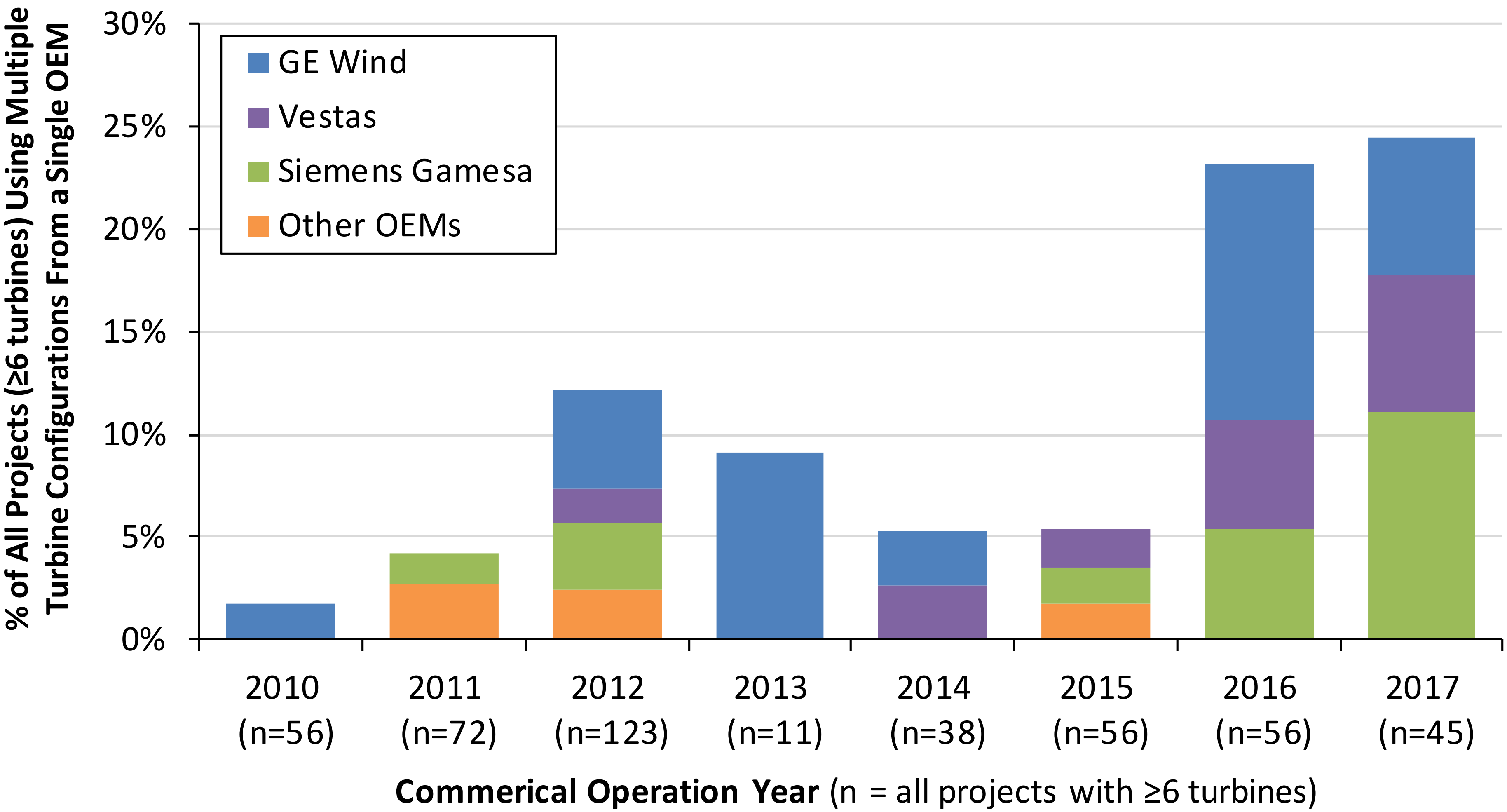
By Wind Resource Quality



Wind Power Projects Planned for the Near Future Are Poised to Continue the Trend of Ever-Taller Turbines

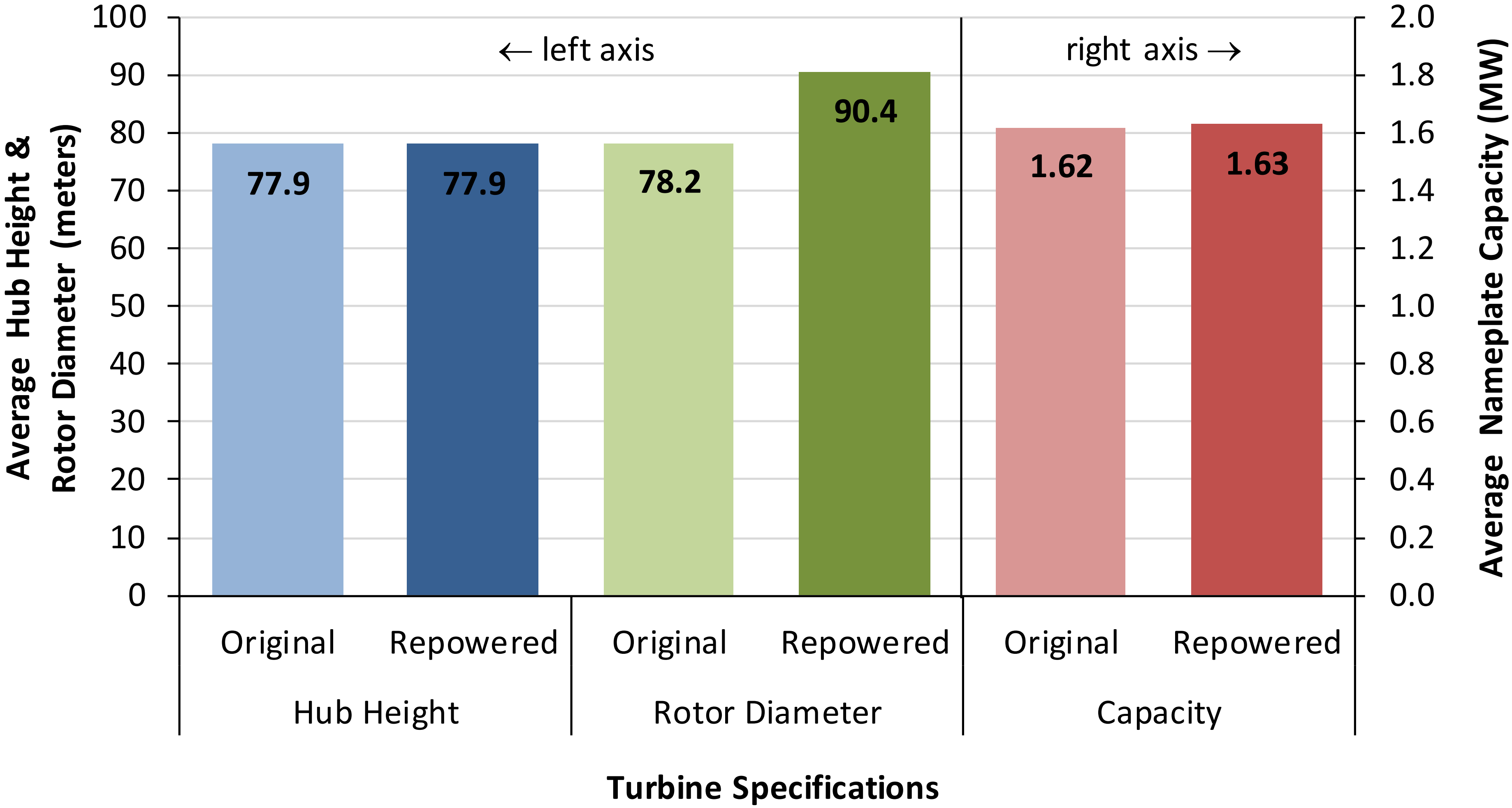


A Large Number of Projects Continued to Employ Multiple Turbine Configurations from a Single Turbine Supplier



Note: Turbine configuration = unique combination of hub height, rotor diameter, and/or capacities

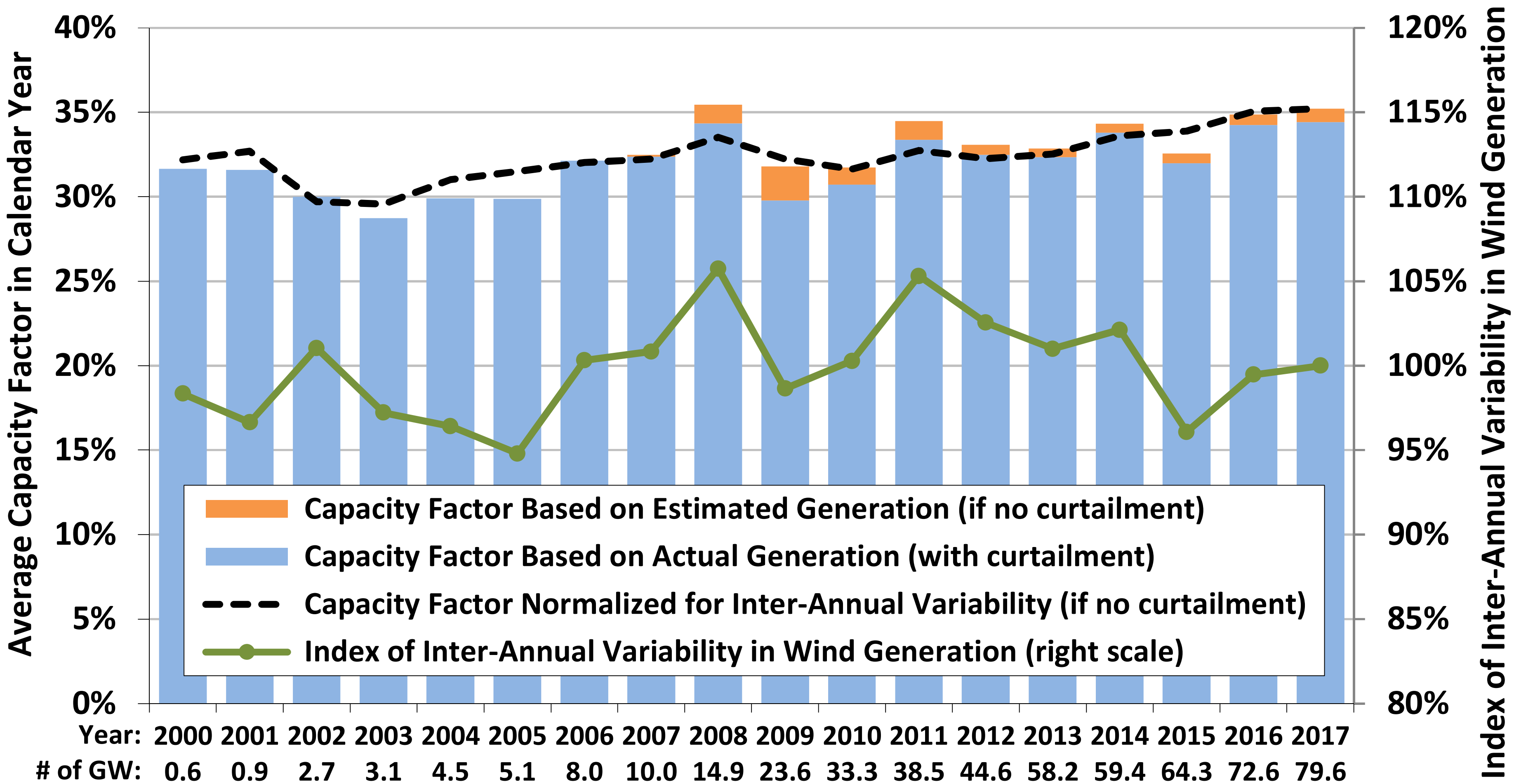
Turbines that Were Partially Repowered in 2017 Now Have Significantly Larger Rotors and Lower Specific Power



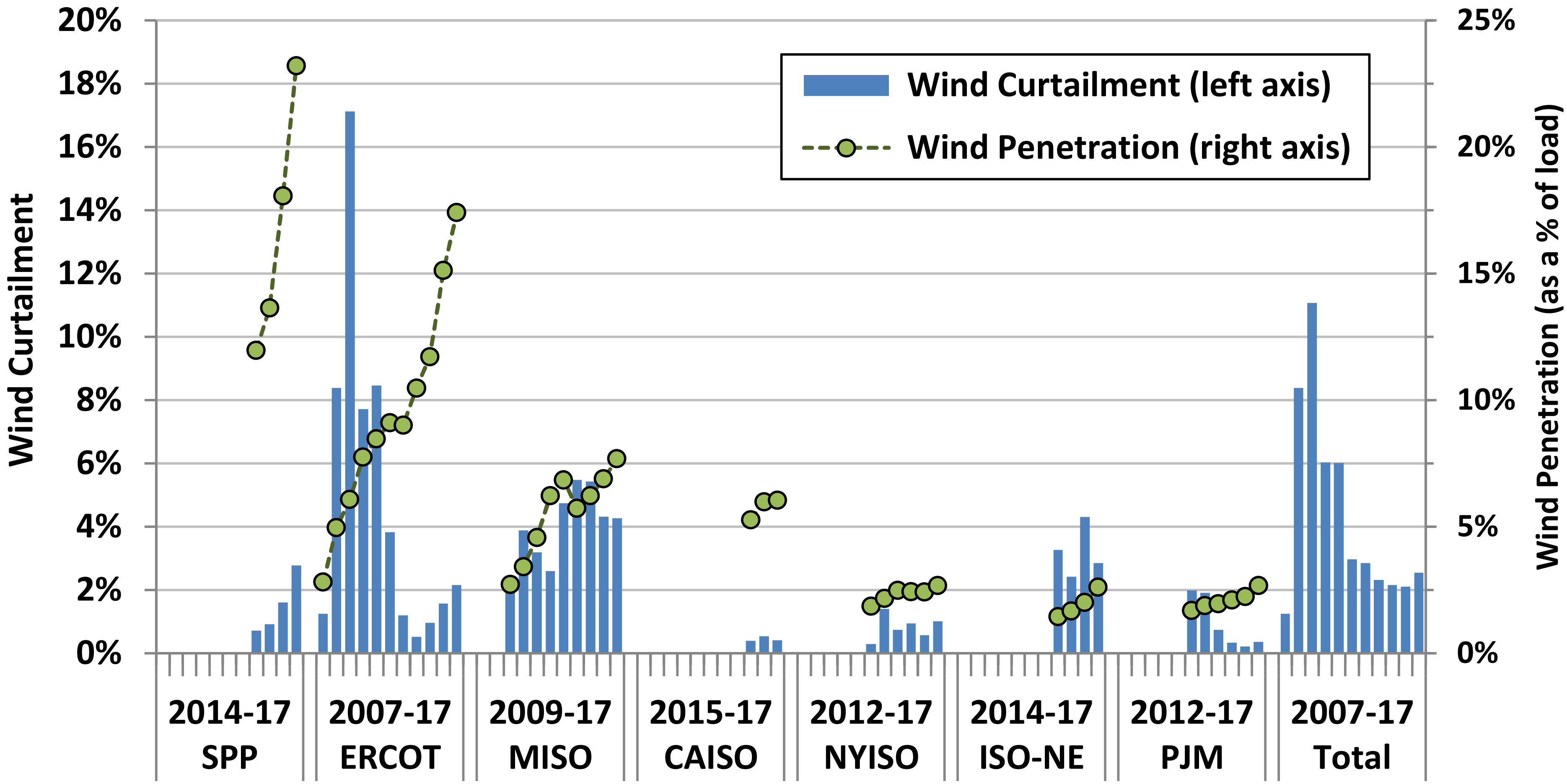
- Average specific power declined from 335 W/m² to 252 W/m² for the 2,131 MW of turbines partially repowered in 2017

Performance Trends

Sample-Wide Capacity Factors Have Gradually Increased, but Are Impacted by Curtailment & Inter-Year Resource Variability

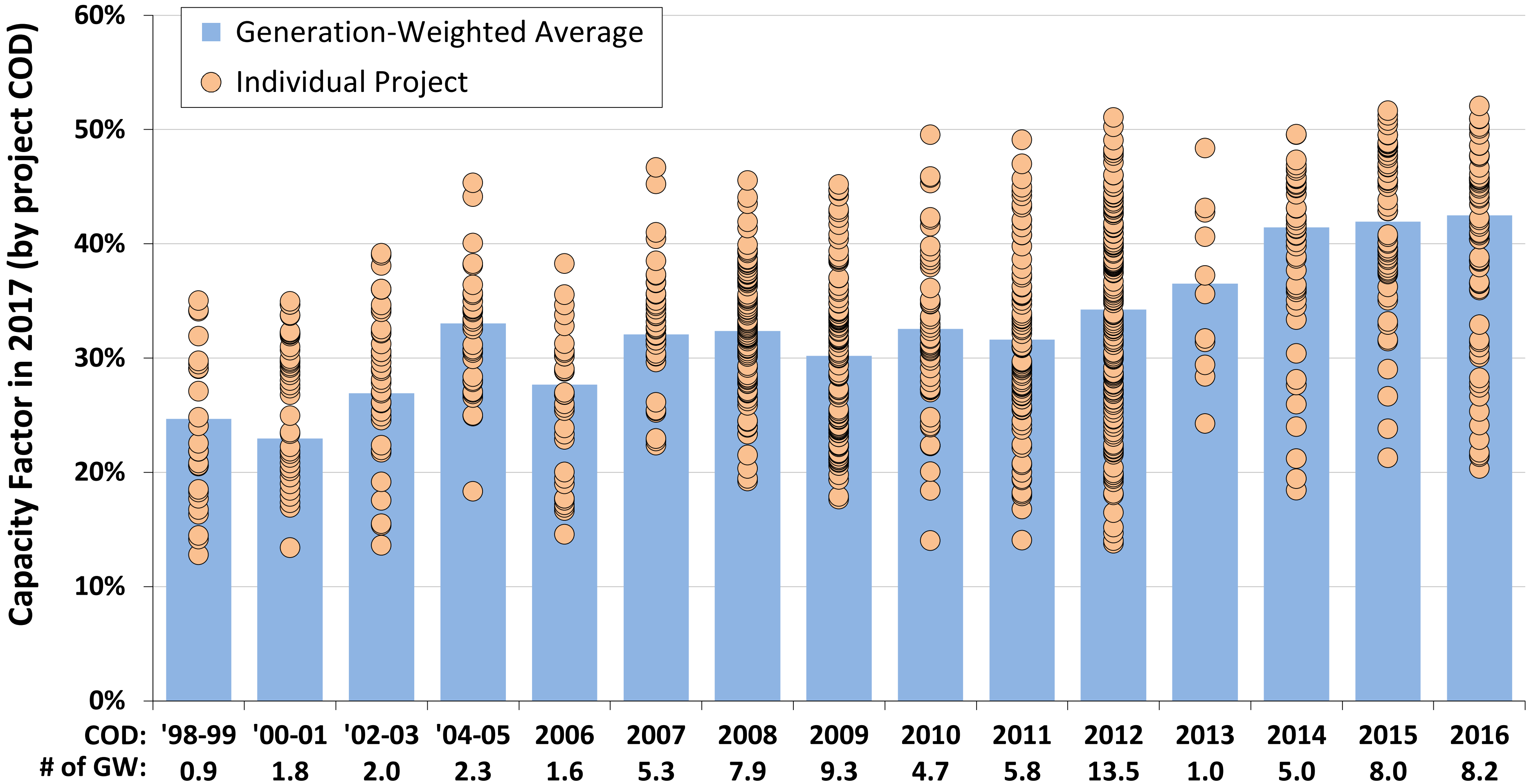


Wind Curtailment Varies by Region; Was Highest in MISO in 2017, but Highest-Ever in ERCOT in 2009

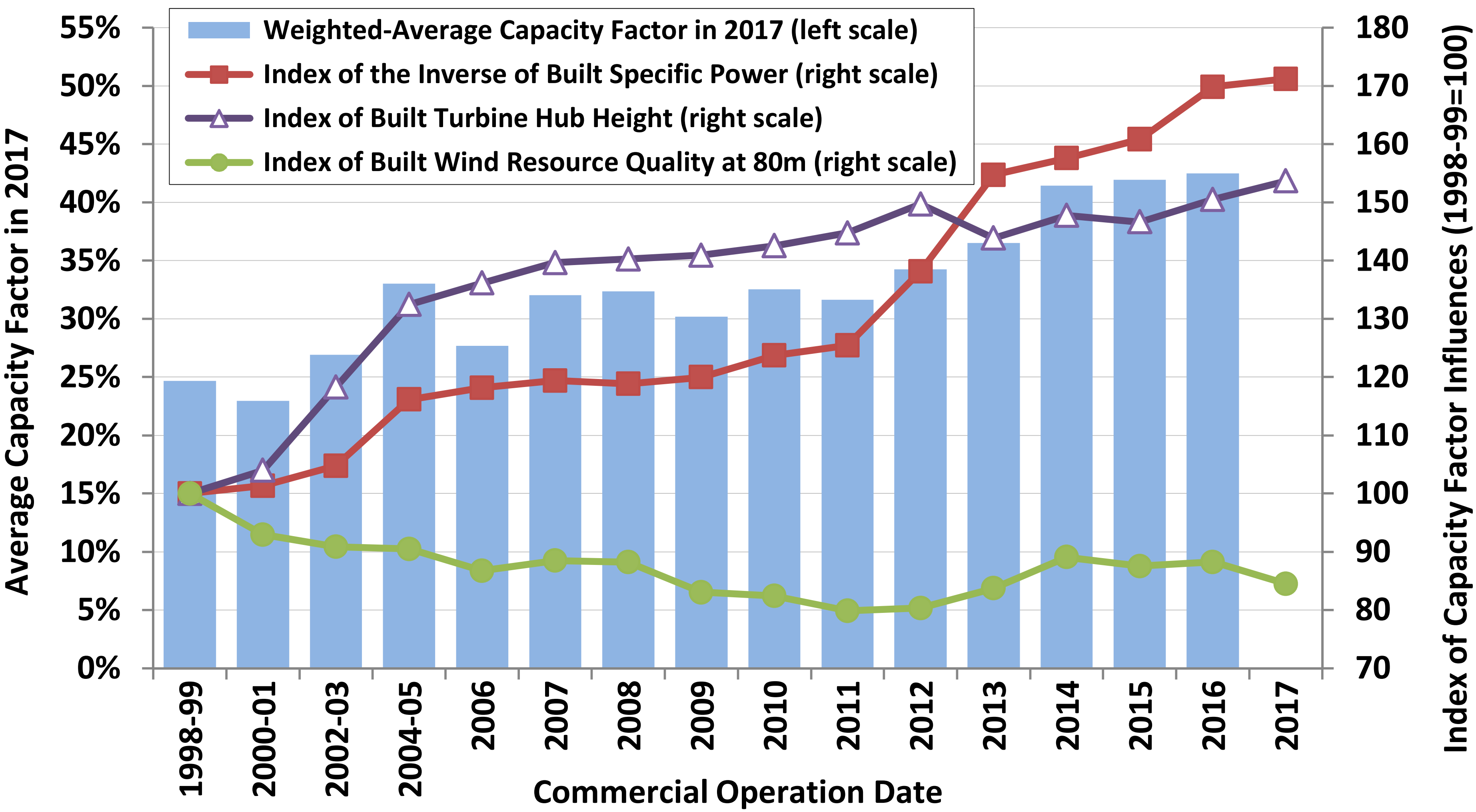


- In areas where curtailment has been particularly problematic in the past—principally in Texas—steps taken to address the issue have born fruit

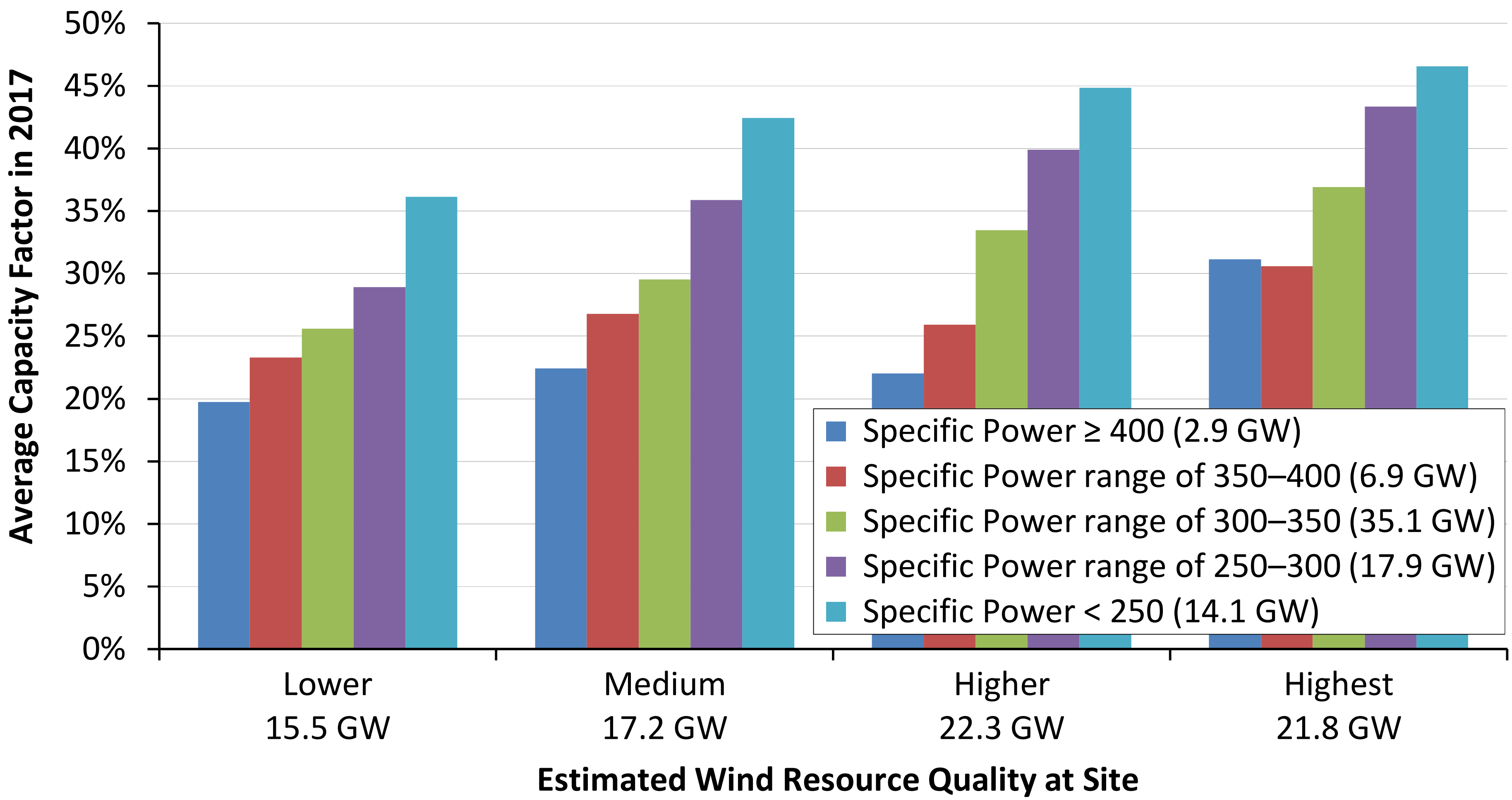
Capacity Factors Have Increased Significantly Over Time, by Online Date (i.e., Commercial Online Date, COD)



Trends Explained by Competing Influences of Lower Specific Power, Higher Hub Heights, Varying Quality Wind Resource Sites

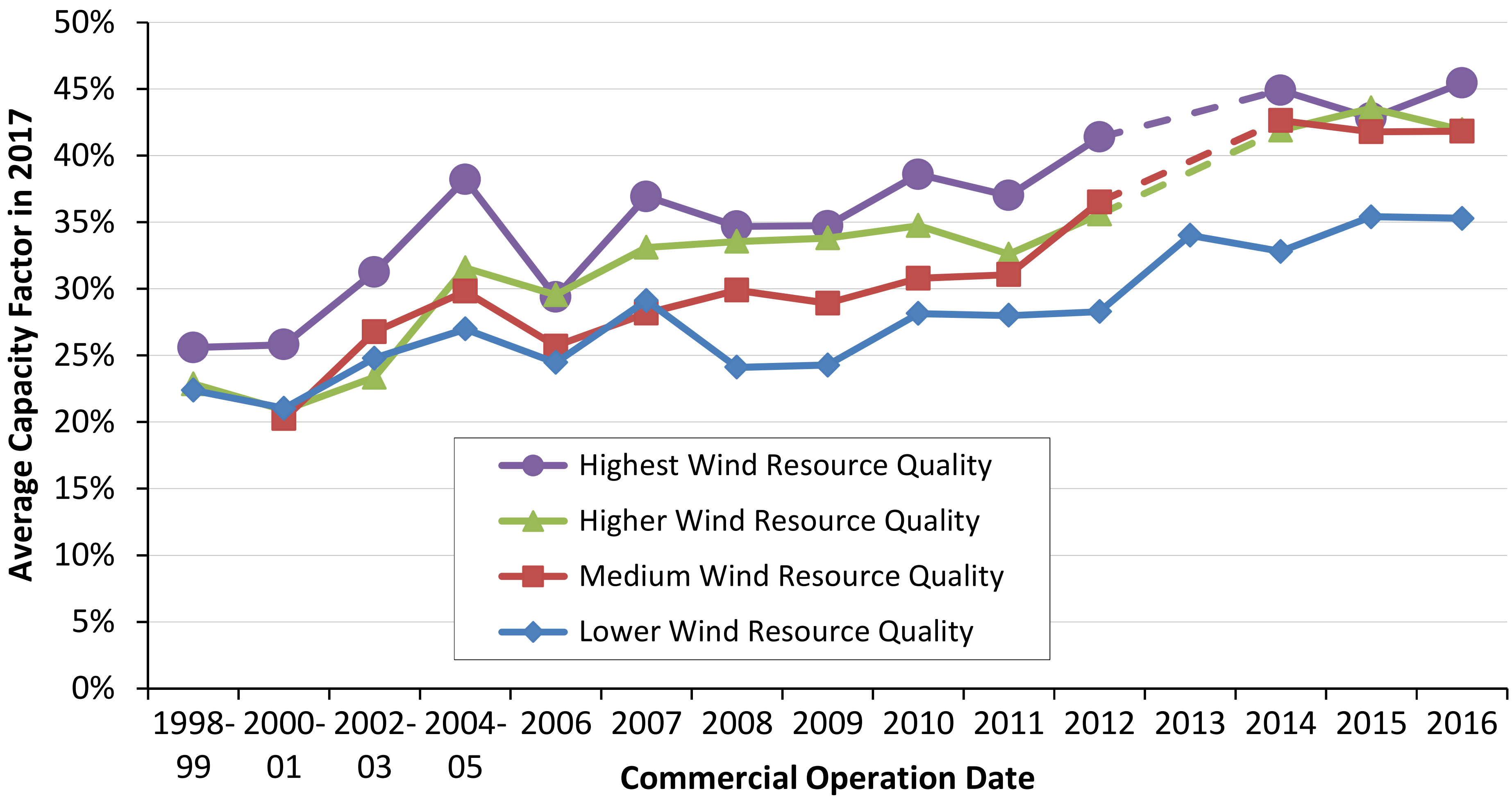


Controlling for Wind Resource Quality and Specific Power Demonstrates Impact of Turbine Evolution

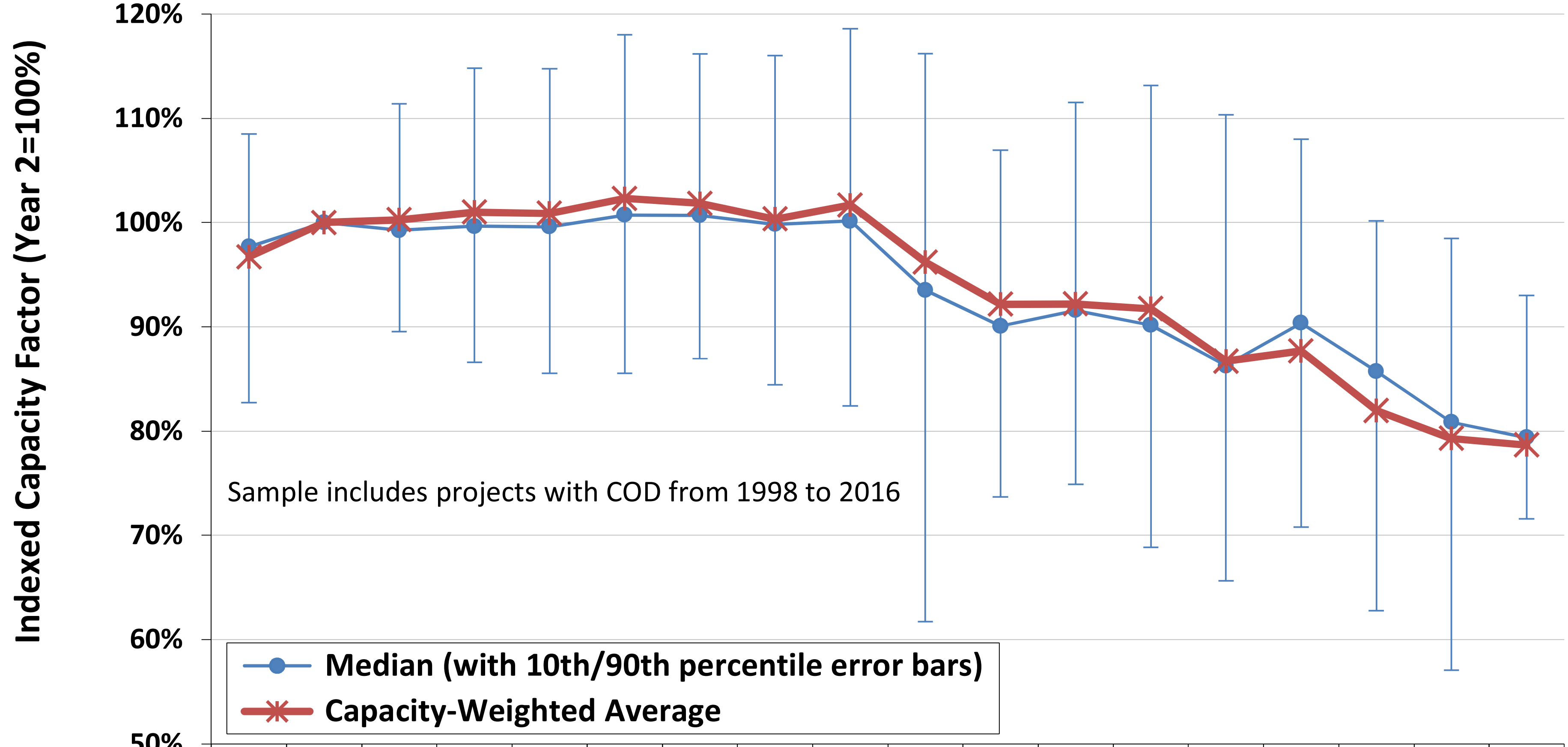


- **Turbine design changes are driving capacity factors higher for projects located in given wind resource regimes**

Controlling for Wind Resource Quality and Commercial Operation Date Also Illustrates Impact of Turbine Evolution

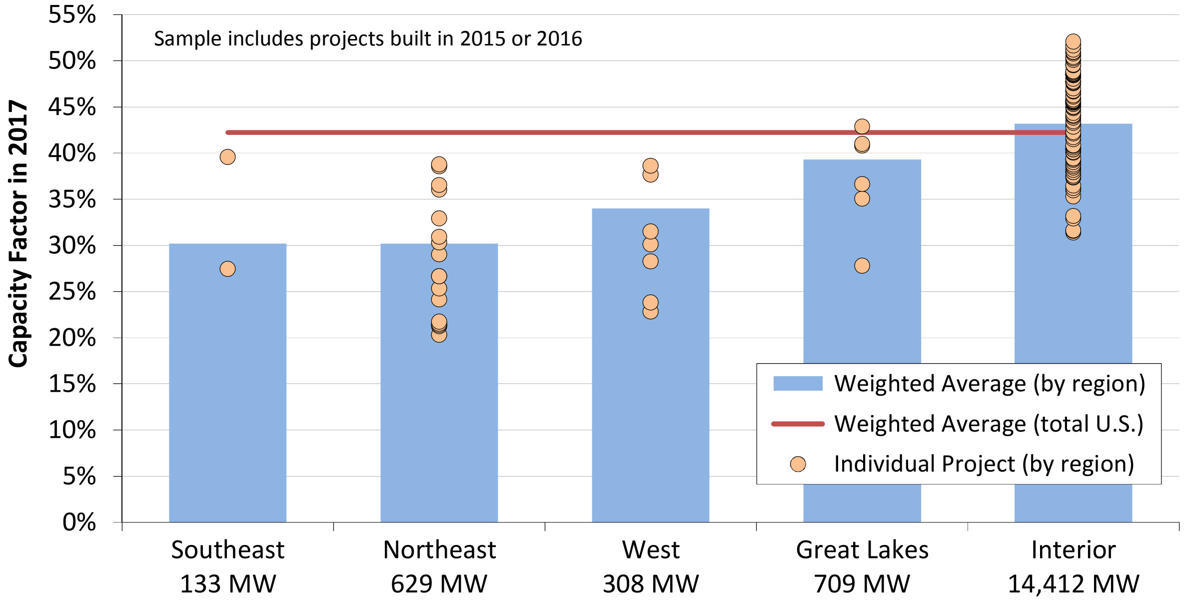


Change in Performance as Projects Age Also Impacts Overall Trends; Performance Degradation Shown After Year Nine

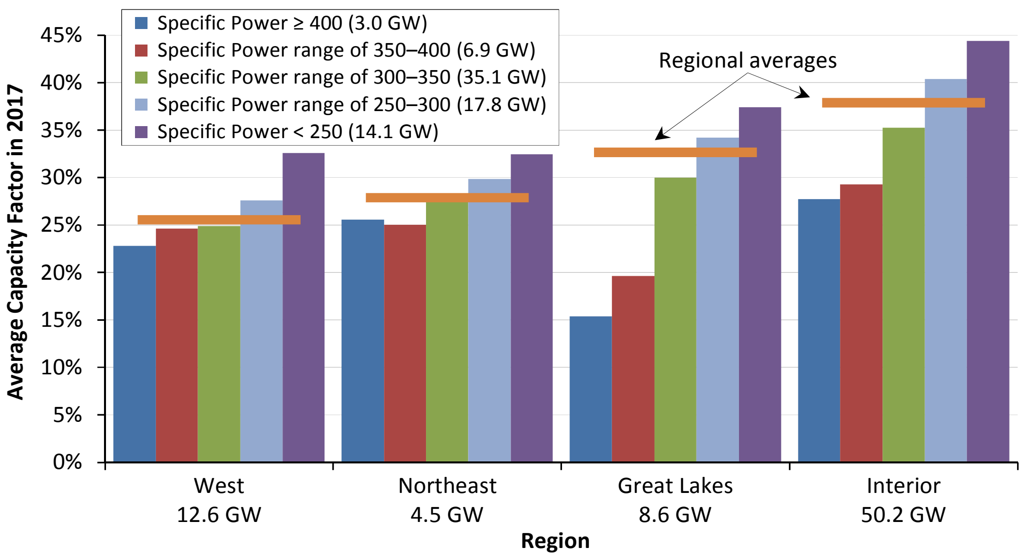


Years post-COD:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Sample GW:	70.8	70.8	62.6	57.8	56.6	42.9	37.3	32.3	22.4	14.7	9.4	6.7	4.6	4.2	2.7	2.3	0.6	0.6

Regional Variations in Capacity Factors Reflect the Strength of the Wind Resource and Adoption of New Turbine Technology

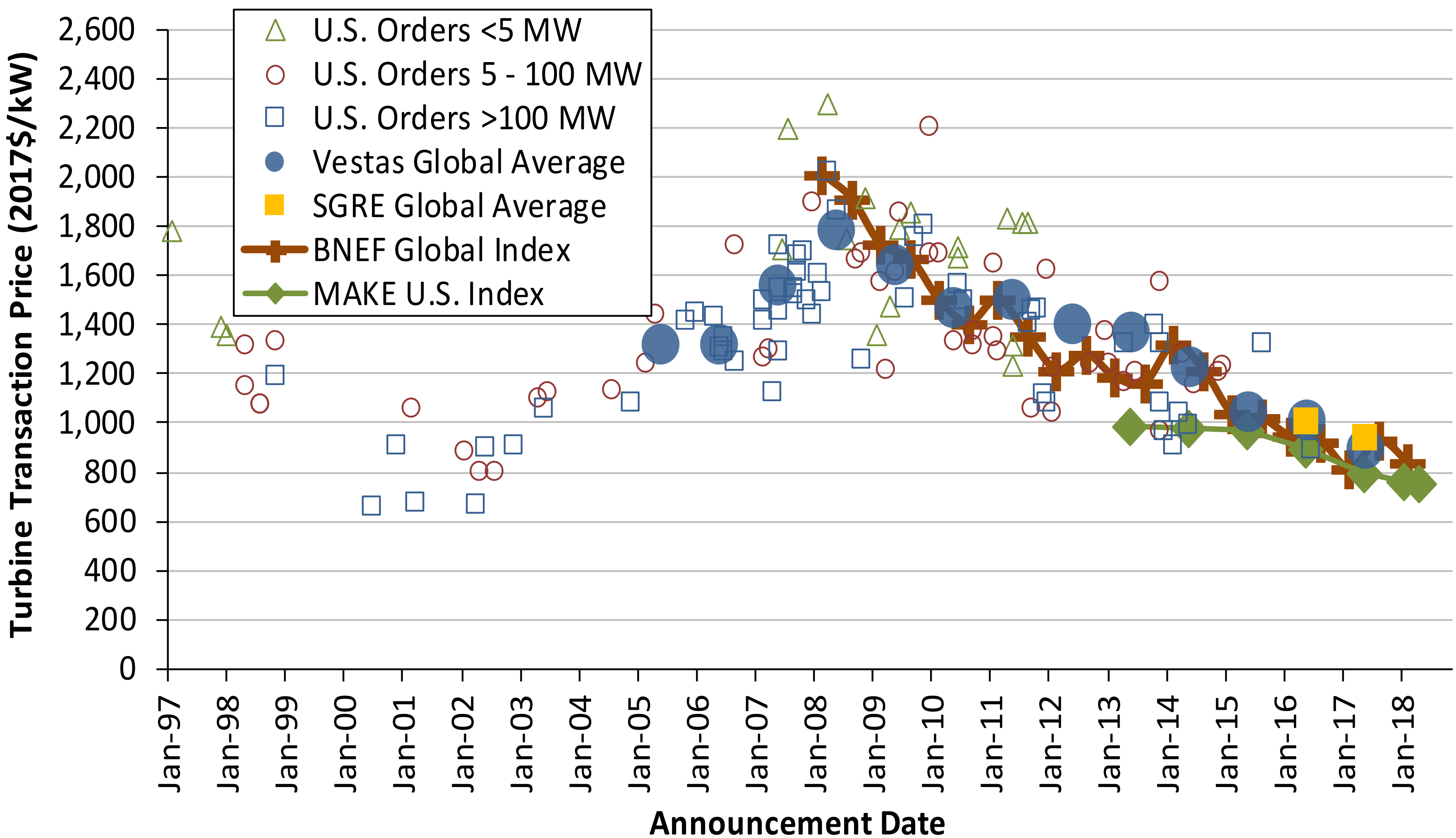


Note: Limited sample size in some regions



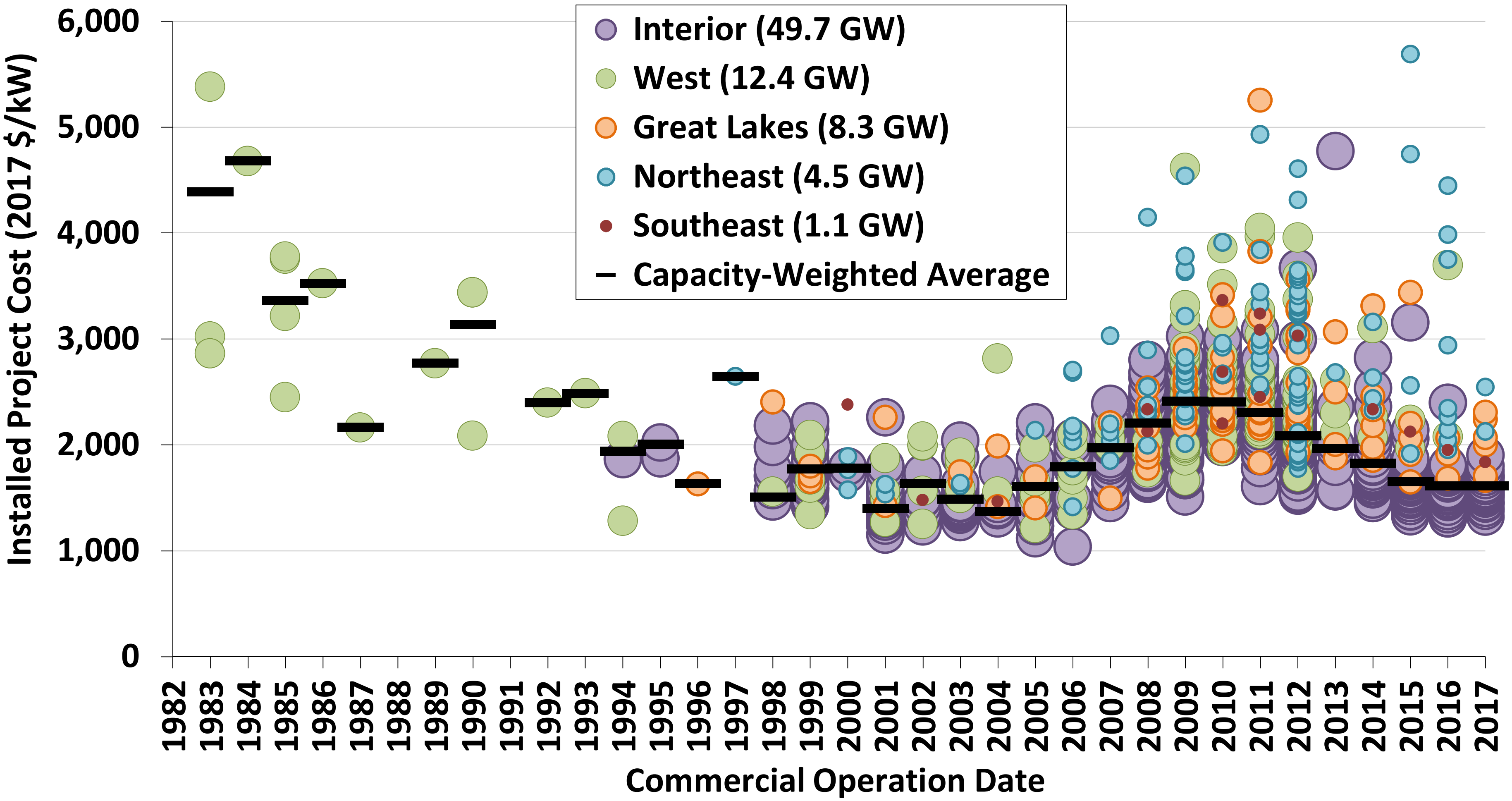
Cost Trends

Wind Turbine Prices Remained Well Below the Levels Seen a Decade Ago



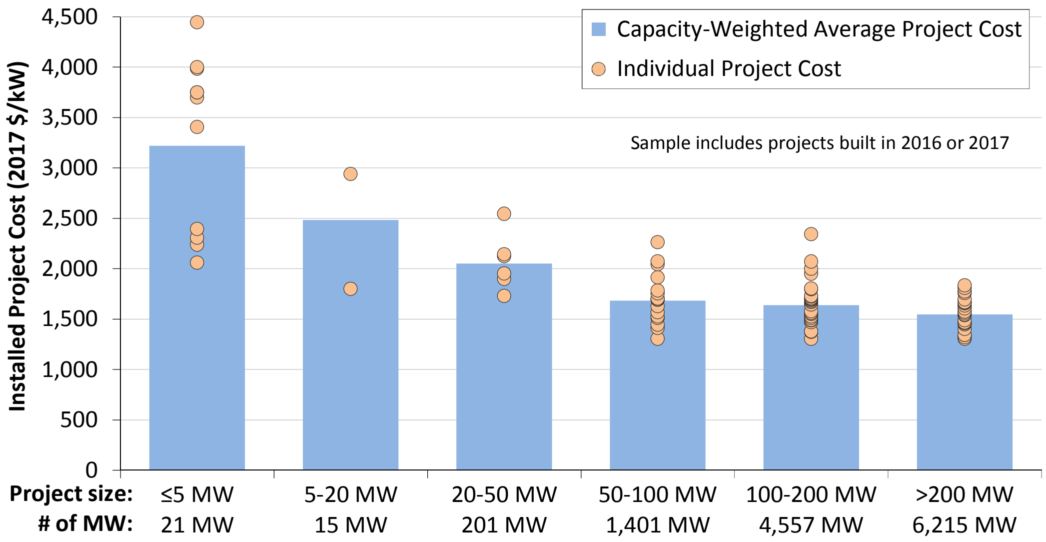
- Recent turbine orders in the range of $750-950/kW

Lower Turbine Prices Have Driven Reductions in Reported Installed Project Costs

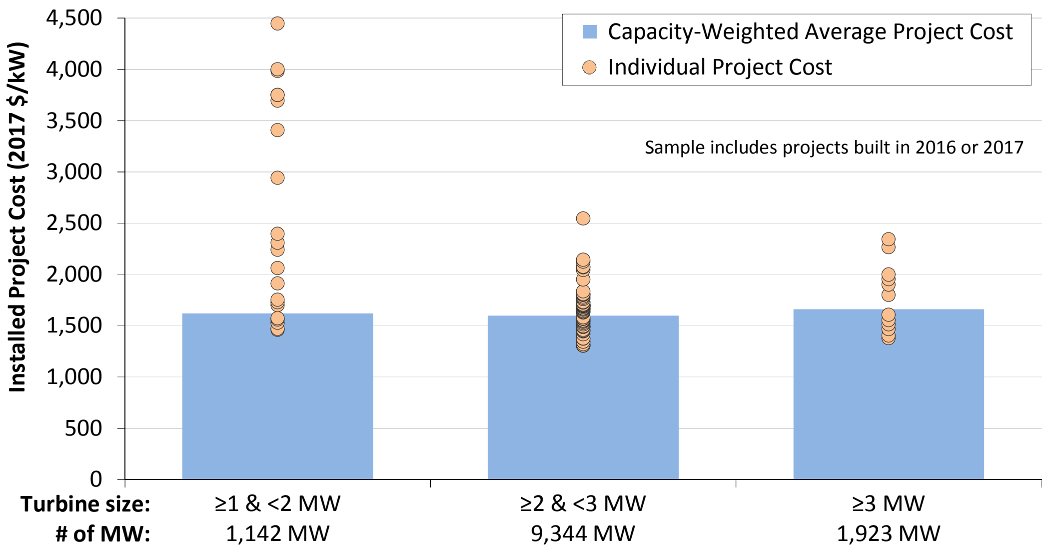


- 2017 projects had an average cost of $1,610/kW, down $795/kW since 2009-2010
- Limited sample of under-construction projects suggest somewhat lower costs in 2018

Economies of Scale Are Apparent, Especially when Moving from Small- to Medium-Sized Projects



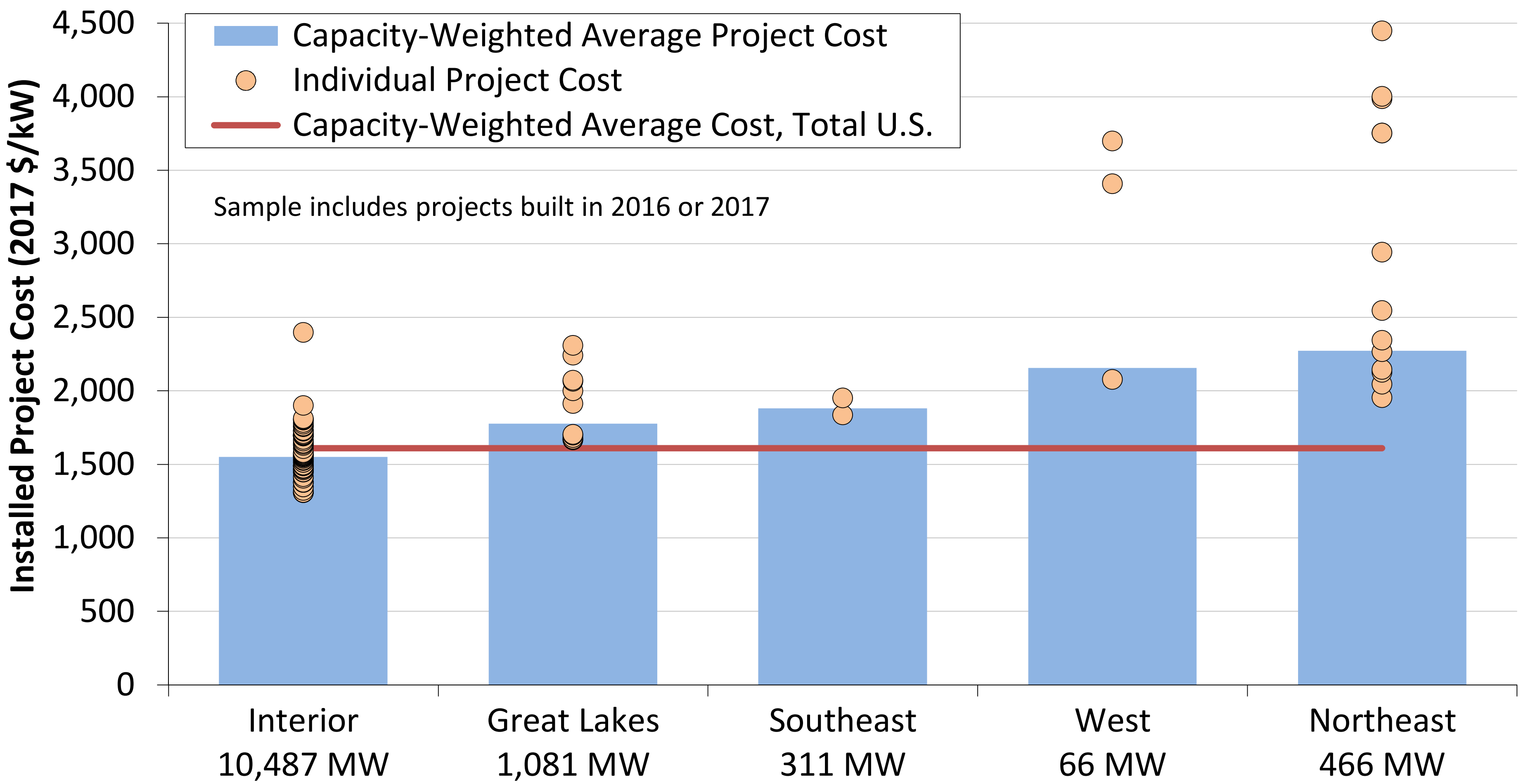
Project Size



Turbine Size

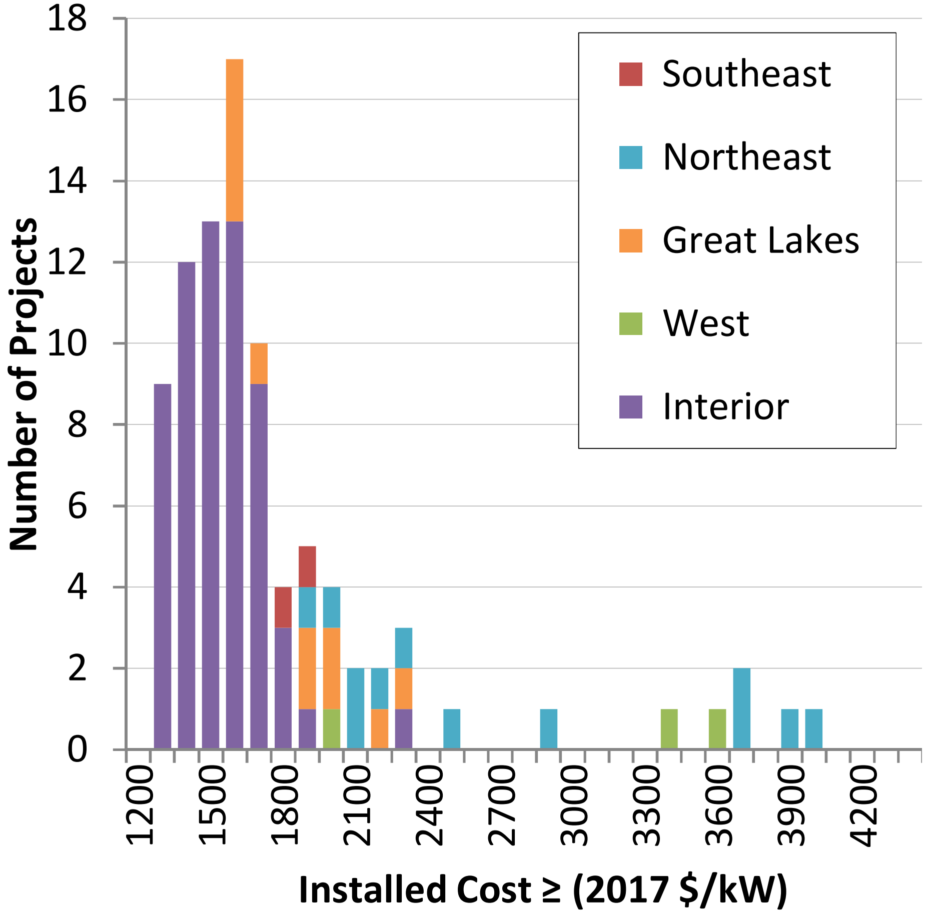
Note: Includes 2016 and 2017 projects

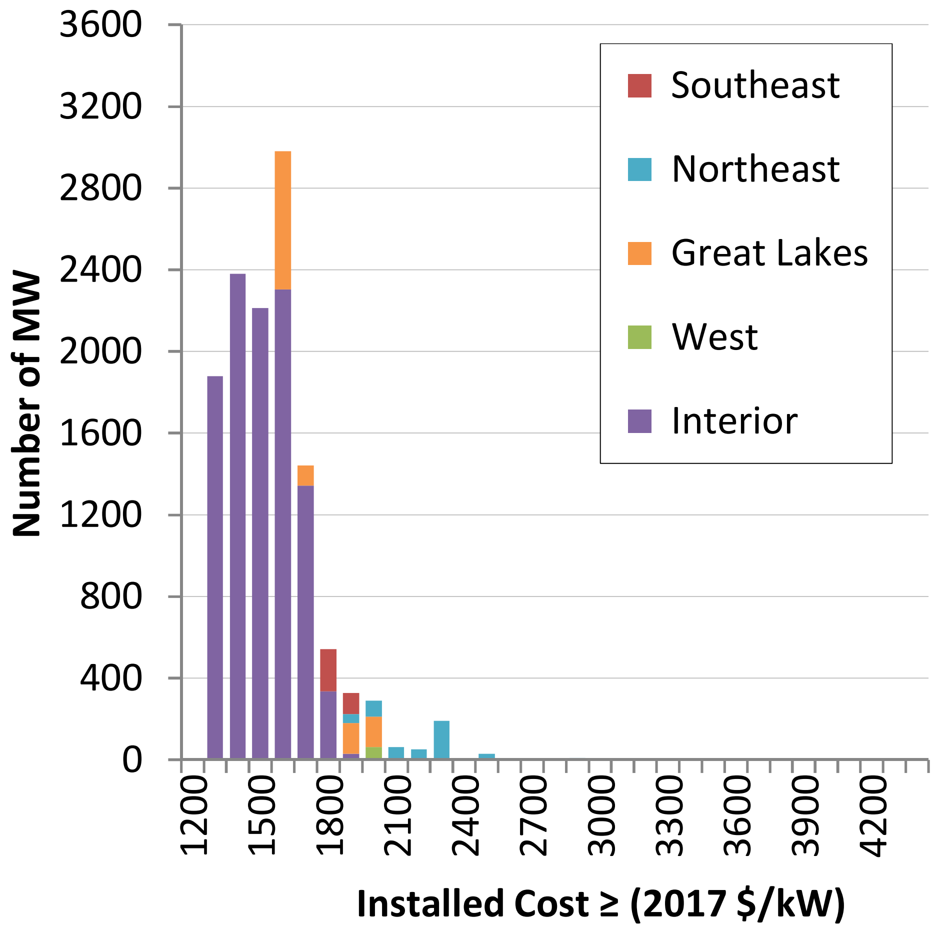
Regional Differences in Average Wind Power Project Costs Are Apparent, but Sample Size Is Limited



Note: Includes 2016 and 2017 projects

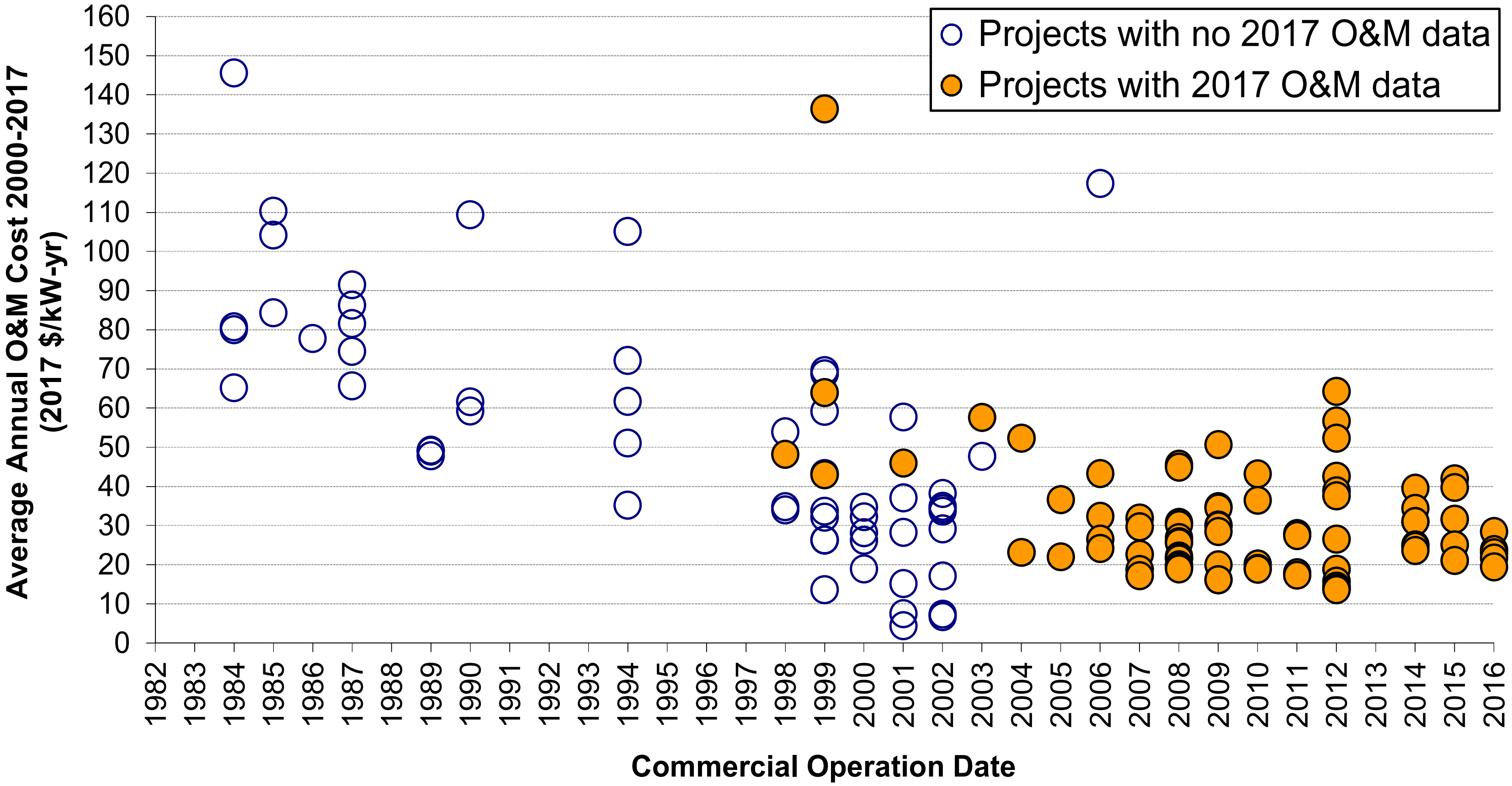
Most Projects—and All of the Low-Cost Projects—Are Located in the Interior; Other Regions Have Higher Costs





Note: Includes 2016 and 2017 projects

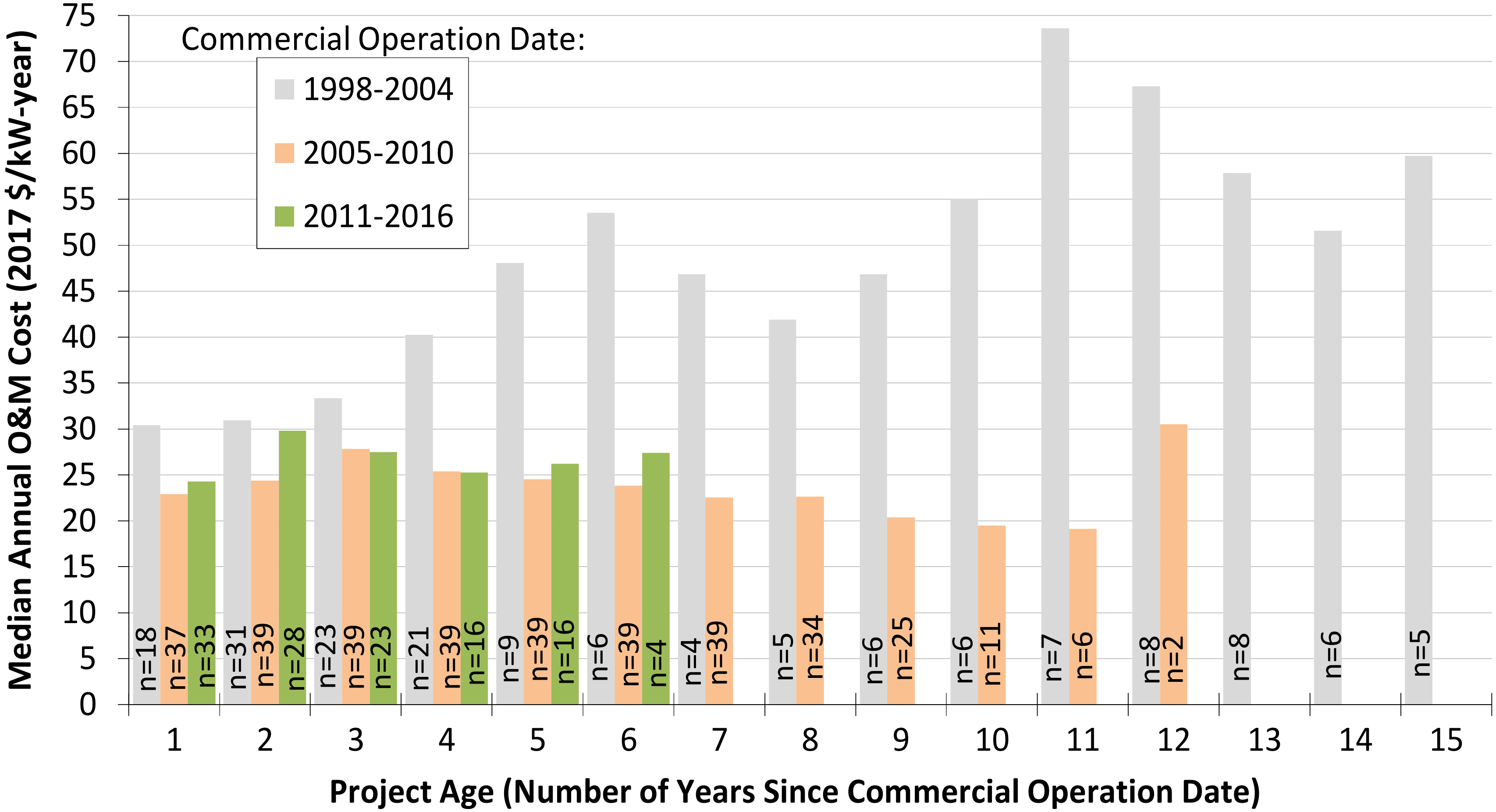
O&M Costs Vary By Project Age and Commercial Operations Date



Note: Sample is limited; few projects in sample have complete records of O&M costs from 2000-17; O&M costs reported here DO NOT include all operating costs

- **Capacity-weighted average 2000-2017 O&M costs for projects built in the 1980s equal $70/kW-year, dropping to $58/kW-year for projects built in the 1990s, to $28/kW-year for projects built in the 2000s and since 2010**

O&M Costs Are Lower for More-Recent Projects, and Increase with Age for the Older Projects



Note: Sample size is limited

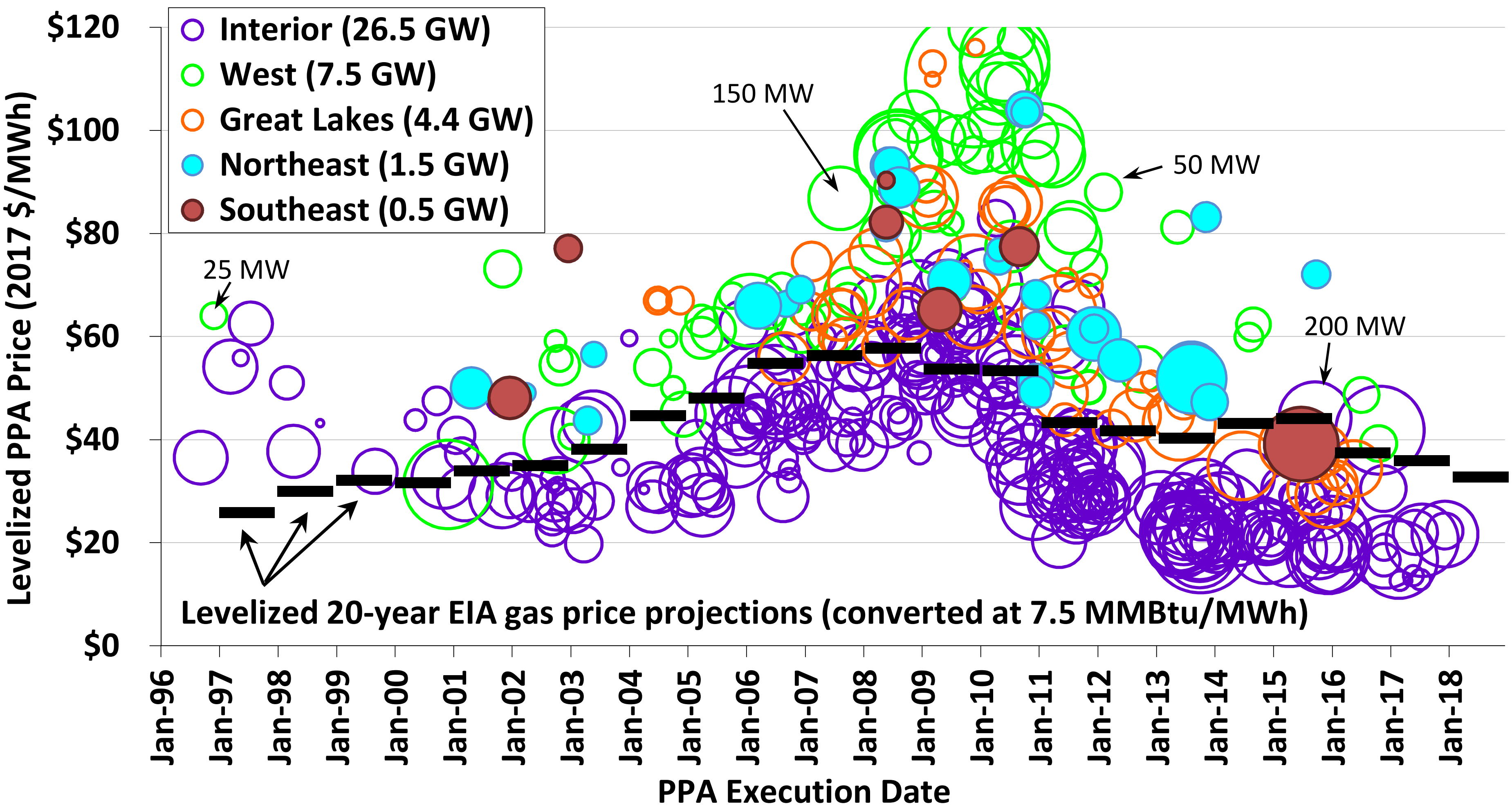
- O&M reported in figure does not include all operating costs: statements from one public company with a large U.S. wind portfolio reports total operating costs in 2017 for projects built in the 2000s of ~$53/kW-year

Wind Power Price Trends

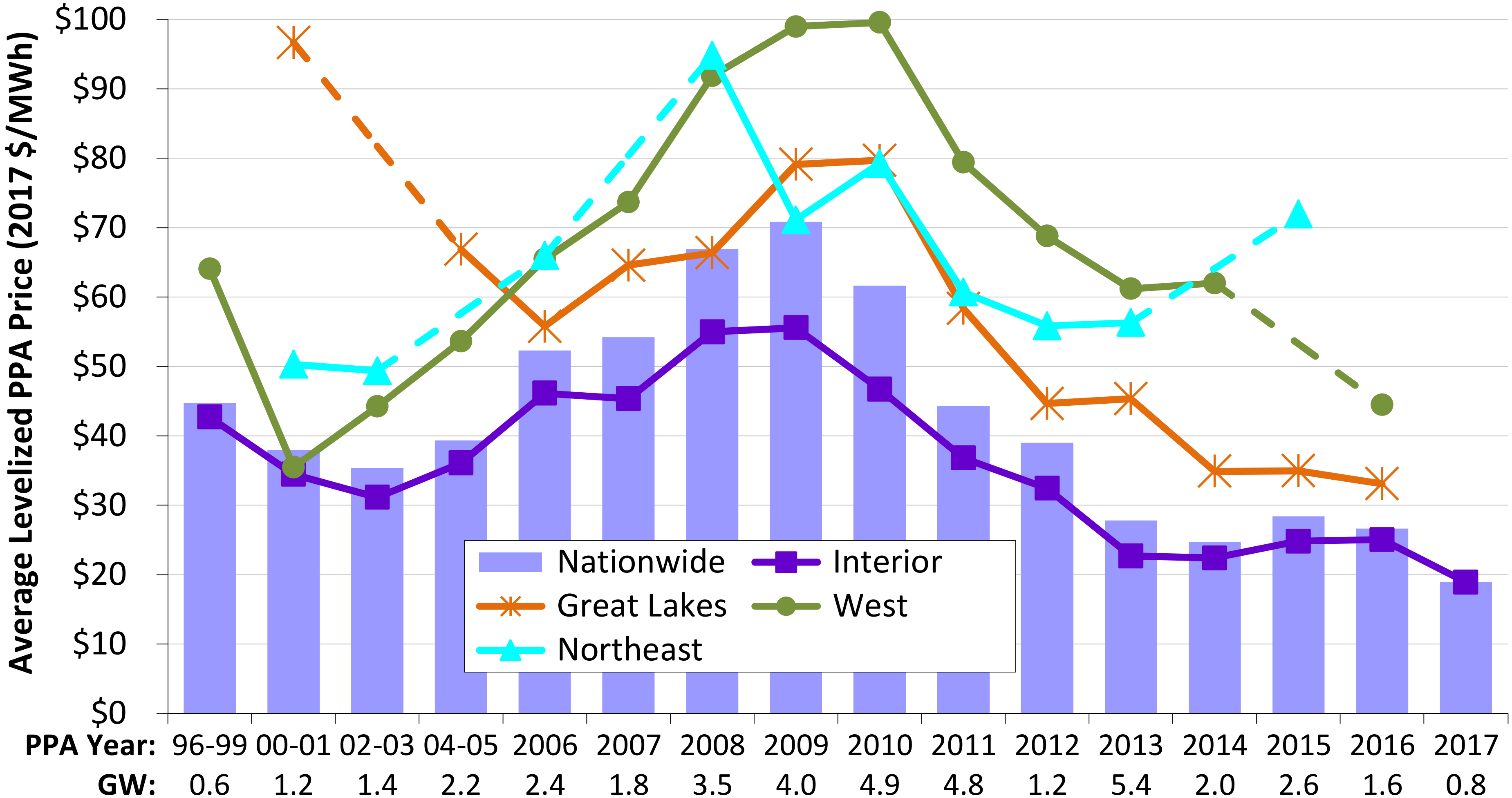
Sample of Wind Power Sales Prices

- **Berkeley Lab collects data on historical wind power sales prices, and long-term PPA prices**
- **PPA sample includes 435 contracts totaling 40,360 MW from projects built from 1998 to 2017, or planned for installation in 2018 or beyond**
- **Prices reflect the bundled price of electricity and RECs as sold by the project owner under a PPA**
  - Dataset excludes merchant plants, projects that sell renewable energy certificates (RECs) separately, and direct retail sales
  - Prices reflect receipt of state and federal incentives (e.g., the PTC or Treasury grant), as well as various local policy and market influences; as a result, prices do not reflect wind energy generation costs

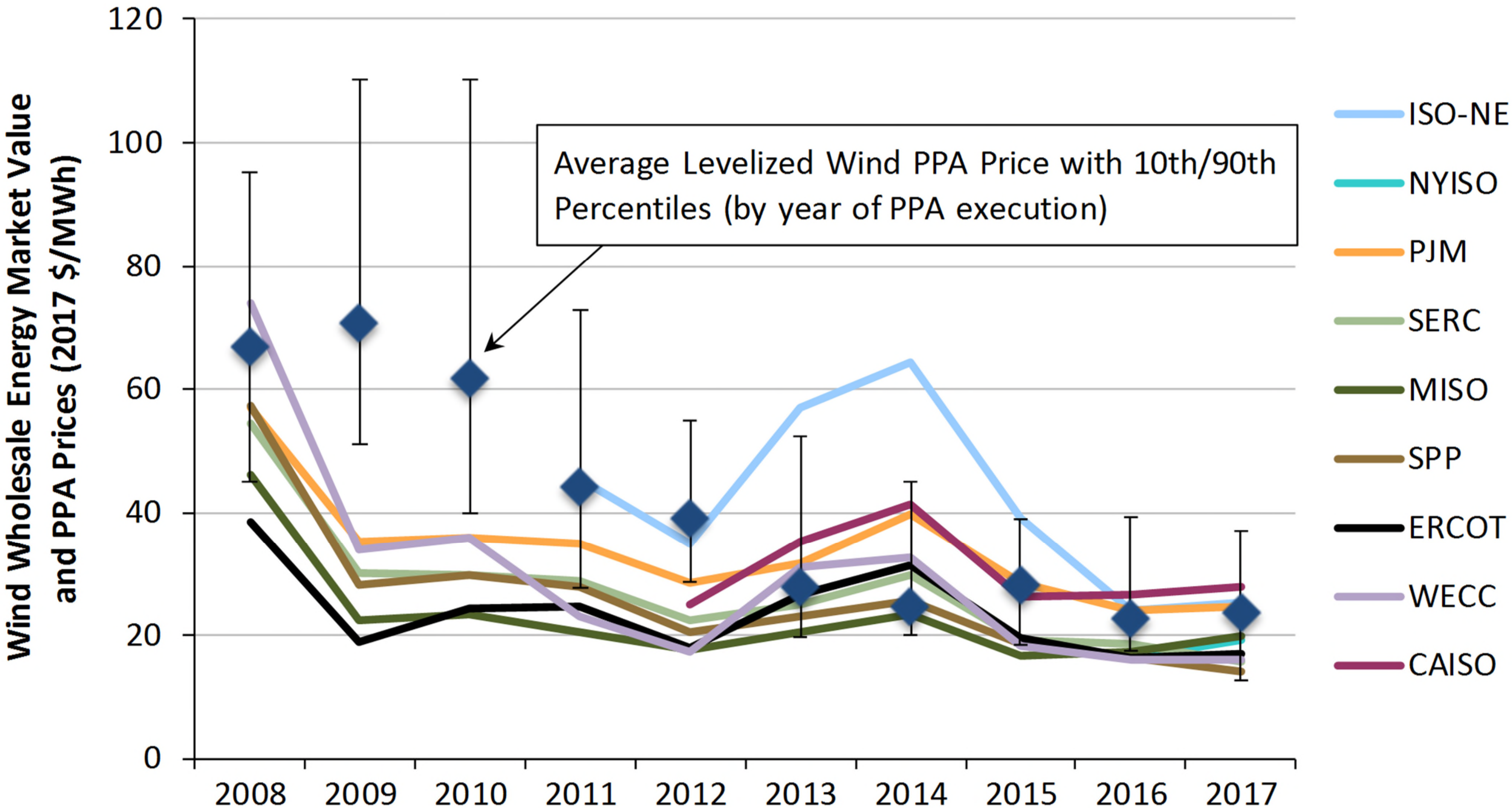
Wind PPA Prices Remain Very Low, and Are Competitive with the Levelized Fuel Cost of a Gas Plant



A Smoother Look at the Time Trend Shows a Steep Decline in Pricing Since 2009; Prices Below $20/MWh in Interior Region

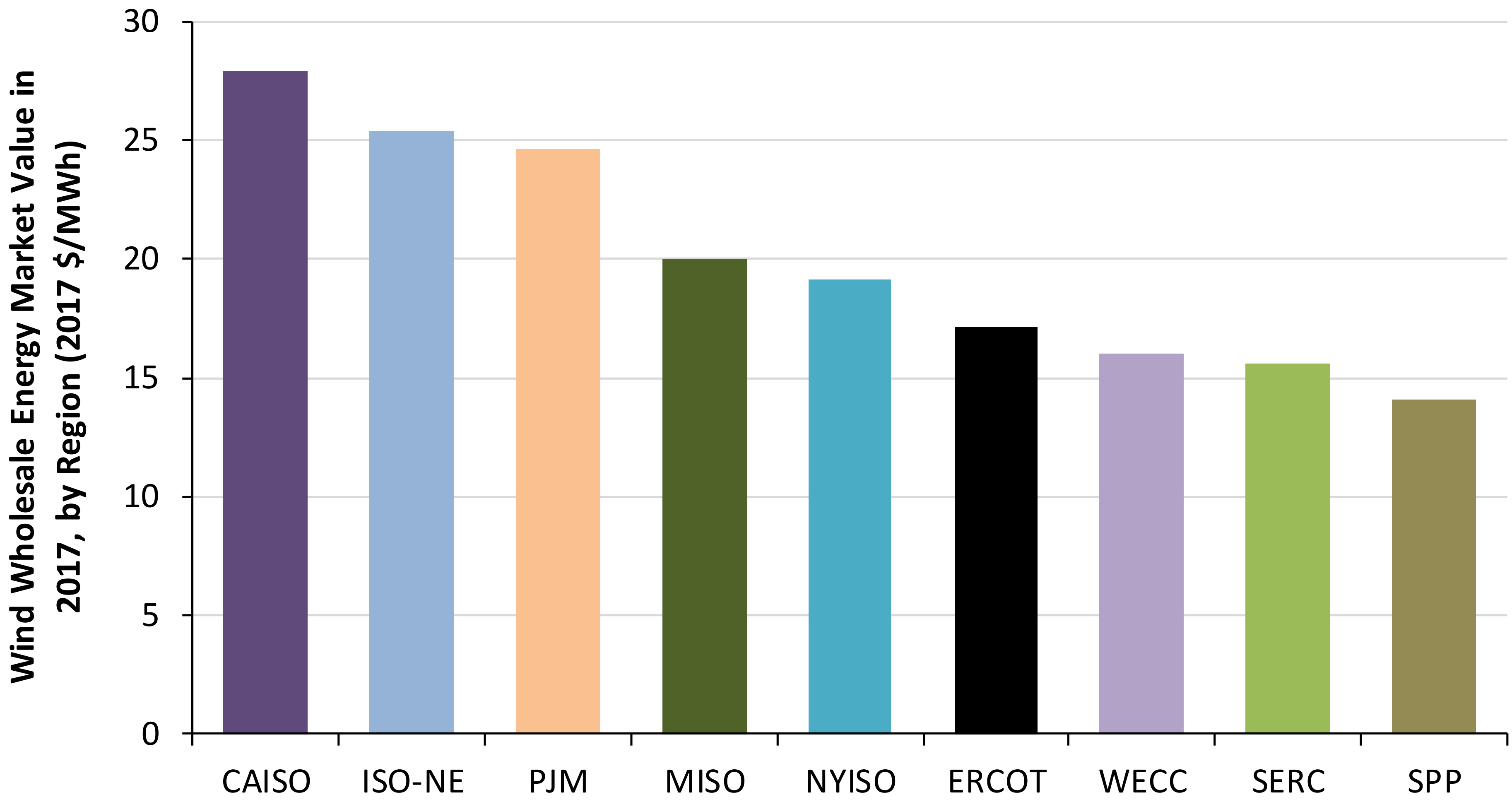


The Relative Competitiveness of Wind Power Has Been Affected by Declines in the Wholesale Market Value of Wind Energy



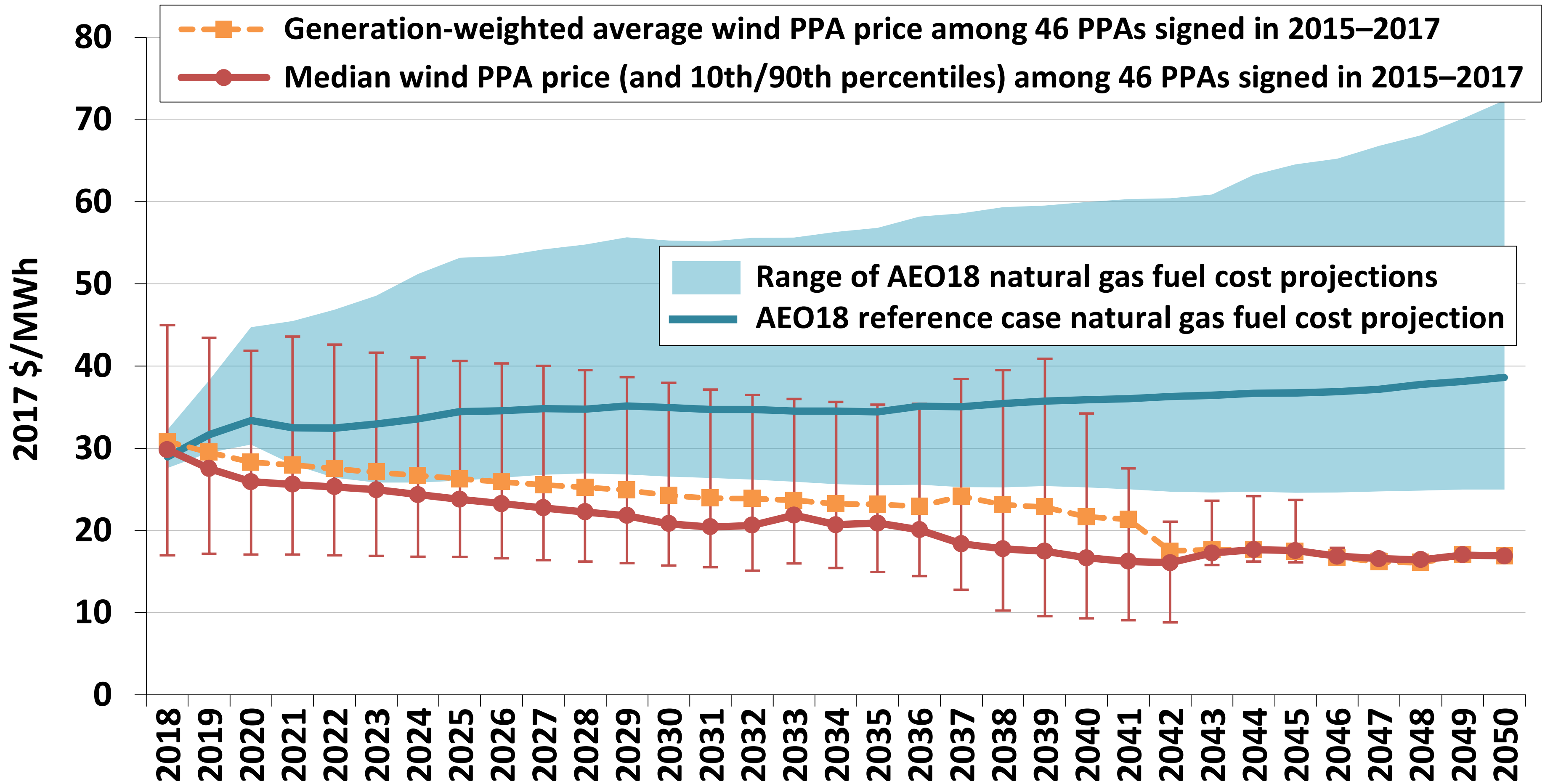
- Wholesale market value considers hourly local wholesale energy price and regional hourly wind output profile; additional capacity value ~$3/MWh available in some regions
- Price comparisons shown are far from perfect—see full report for caveats

The Wholesale Energy Market Value of Wind Energy in 2017 Varied by Region: Lowest in SPP, Highest in CAISO



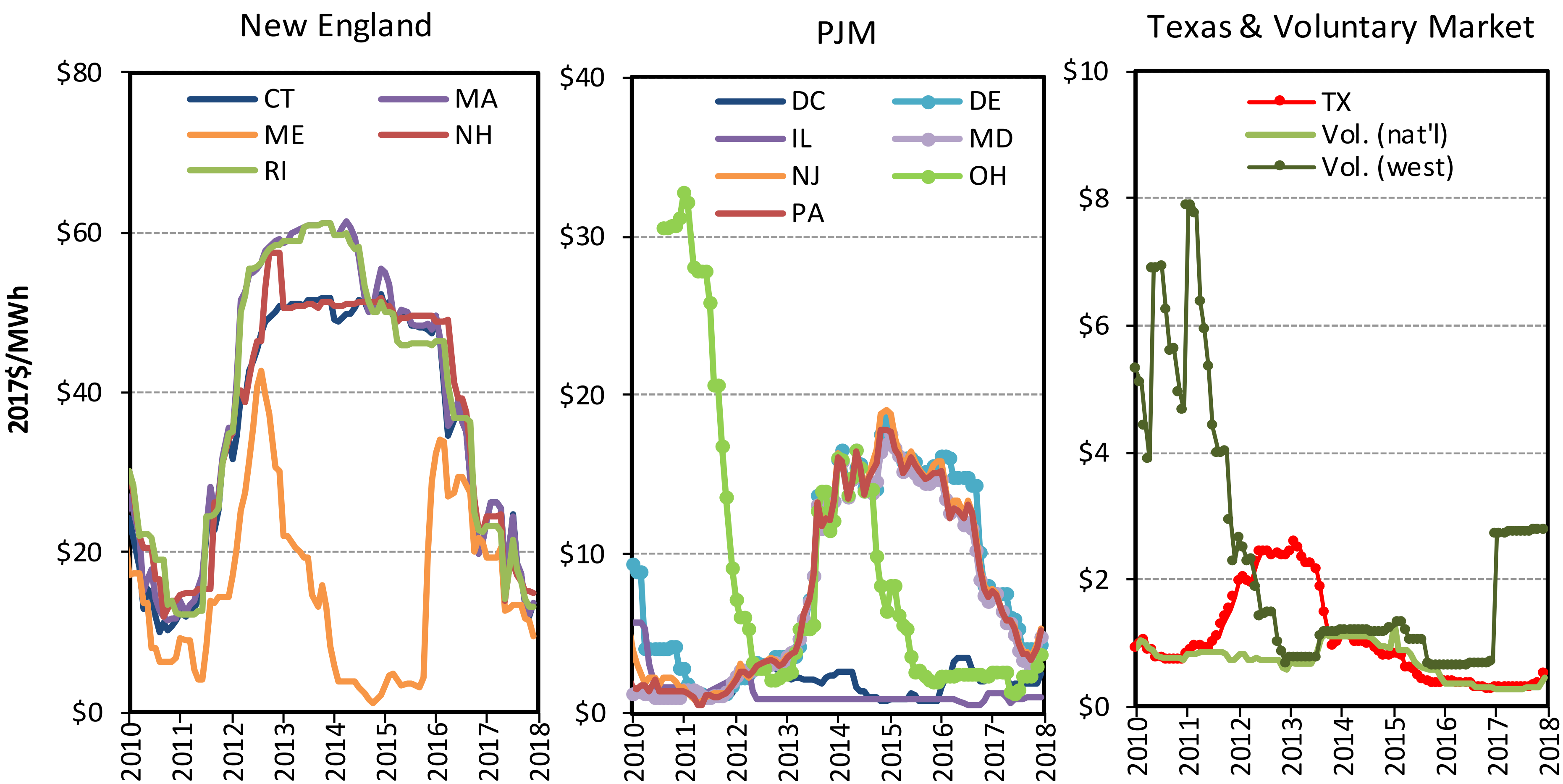
- Price comparisons shown are far from perfect—see full report for caveats

Recent Wind Prices Are Competitive with the Expected Future Cost of Burning Fuel in Natural Gas Plants



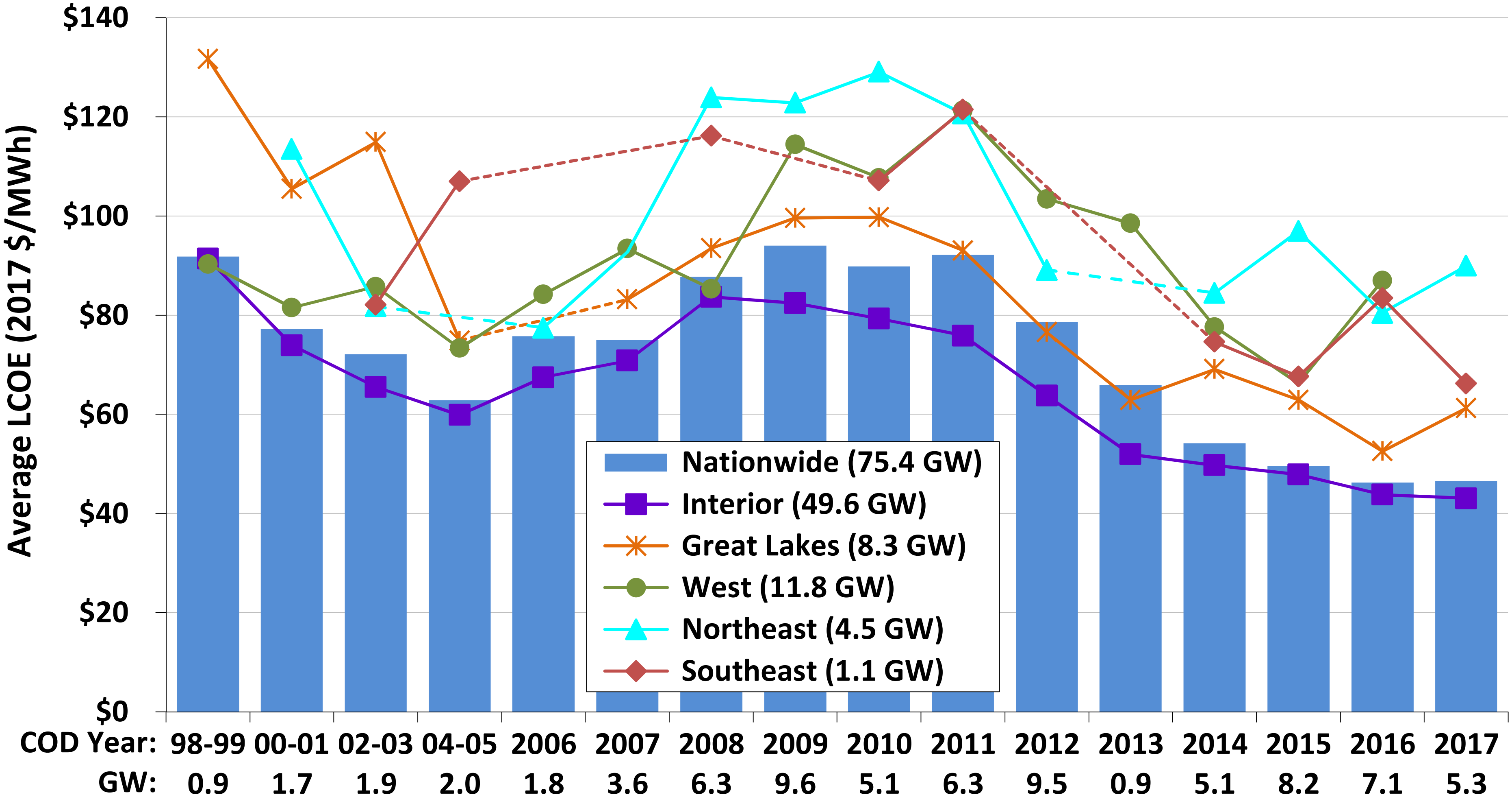
- Price comparisons shown are far from perfect—see full report for caveats

Renewable Energy Certificate (REC) Prices in Key RPS Markets Fell Significantly in 2017, Reflecting Growing Supplies



- REC prices vary by: market type (compliance vs. voluntary); geographic region; specific design of state RPS policies

The Levelized Cost of Wind Energy Is at an All-Time Low



- Estimates reflect variations in installed cost, capacity factors, operational costs, and cost of financing; include accelerated depreciation but exclude PTC

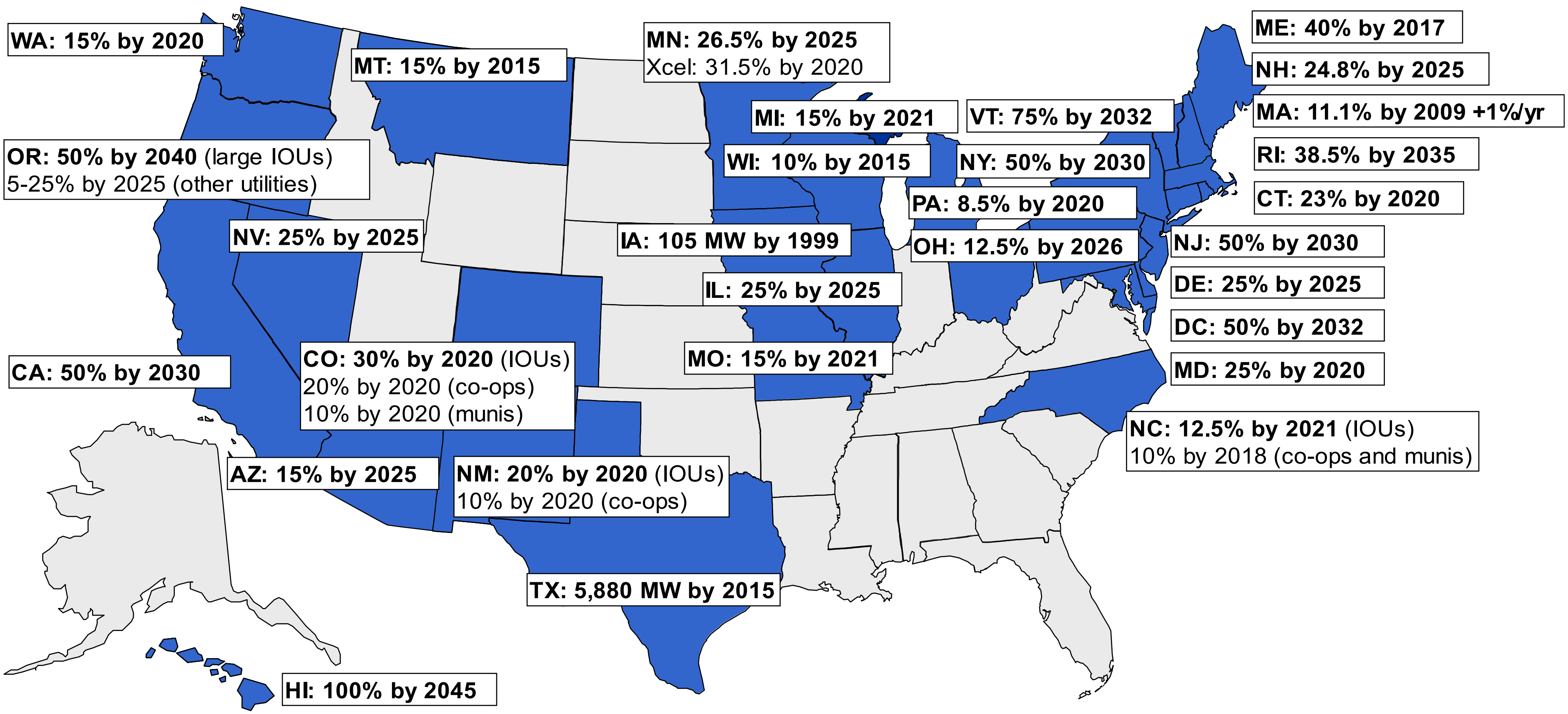
Policy and Market Drivers

The Federal Production Tax Credit (PTC) Remains One of the Core Motivators for Wind Power Deployment

Legislation	Date Enacted	Start of PTC Window	End of PTC Window	Effective PTC Planning Window (considering lapses and early extensions)
Energy Policy Act of 1992	10/24/1992	1/1/1994	6/30/1999	80 months
>5-month lapse before expired PTC was extended				
Ticket to Work and Work Incentives Improvement Act of 1999	12/19/1999	7/1/1999	12/31/2001	24 months
>2-month lapse before expired PTC was extended				
Job Creation and Worker Assistance Act	3/9/2002	1/1/2002	12/31/2003	22 months
>9-month lapse before expired PTC was extended				
The Working Families Tax Relief Act	10/4/2004	1/1/2004	12/31/2005	15 months
Energy Policy Act of 2005	8/8/2005	1/1/2006	12/31/2007	29 months
Tax Relief and Healthcare Act of 2006	12/20/2006	1/1/2008	12/31/2008	24 months
Emergency Economic Stabilization Act of 2008	10/3/2008	1/1/2009	12/31/2009	15 months
The American Recovery and Reinvestment Act of 2009	2/17/2009	1/1/2010	12/31/2012	46 months
2-day lapse before expired PTC was extended				
American Taxpayer Relief Act of 2012	1/2/2013	1/1/2013	Start construction by 12/31/2013	12 months (in which to start construction)
>11-month lapse before expired PTC was extended				
Tax Increase Prevention Act of 2014	12/19/2014	1/1/2014	Start construction by 12/31/2014	2 weeks (in which to start construction)
>11-month lapse before expired PTC was extended				
Consolidated Appropriations Act of 2016	12/18/2015	1/1/2015	Start construction by 12/31/2016	12 months to start construction and receive 100% PTC value
			Start construction by 12/31/2017	24 months to start construction and receive 80% PTC value
			Start construction by 12/31/2018	36 months to start construction and receive 60% PTC value
			Start construction by 12/31/2019	48 months to start construction and receive 40% PTC value

- **5-year extension of PTC in 2015, plus guidance allowing 4 years for project completion after the start of construction**
- **PTC phase-out, with progressive reduction in the value of the credit for projects starting construction after 2016**
- **PTC phases out in 20%-per-year increments for projects starting construction in 2017 (80% PTC value), 2018 (60%), 2019 (40%)**

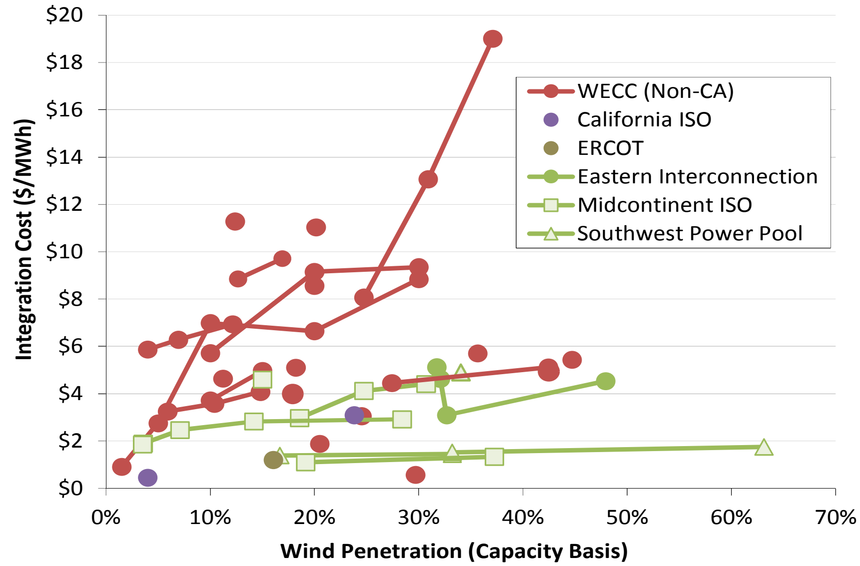
State Policies Help Direct the Location and Amount of Wind Development, but Wind Growth is Outpacing State Targets



- 29 states and D.C. have mandatory RPS programs, which can support ~4.5 GW/yr of renewable energy additions on average through 2030 (less for wind specifically)

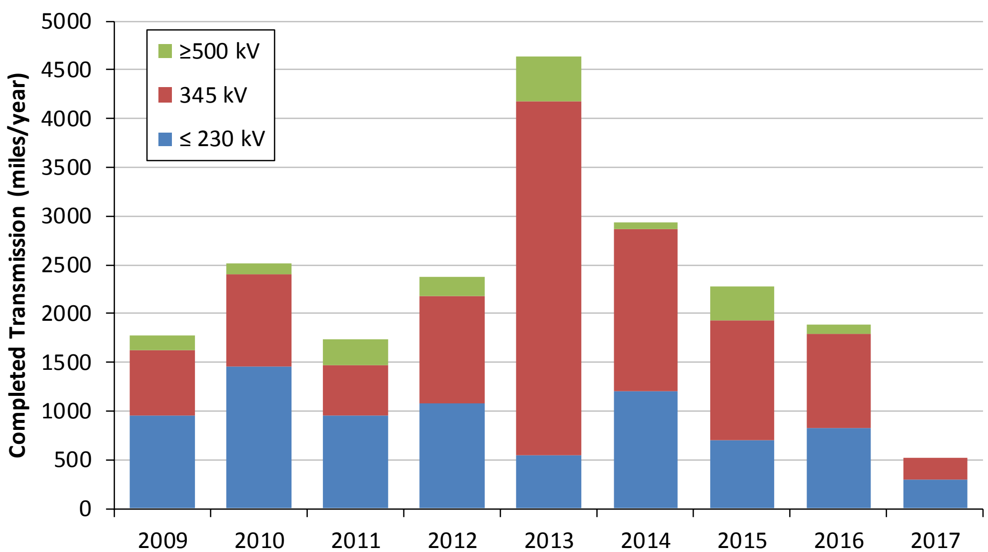
System Operators Are Implementing Methods to Accommodate Increased Penetrations of Wind

Integrating wind energy into power systems is manageable, but not free of additional costs



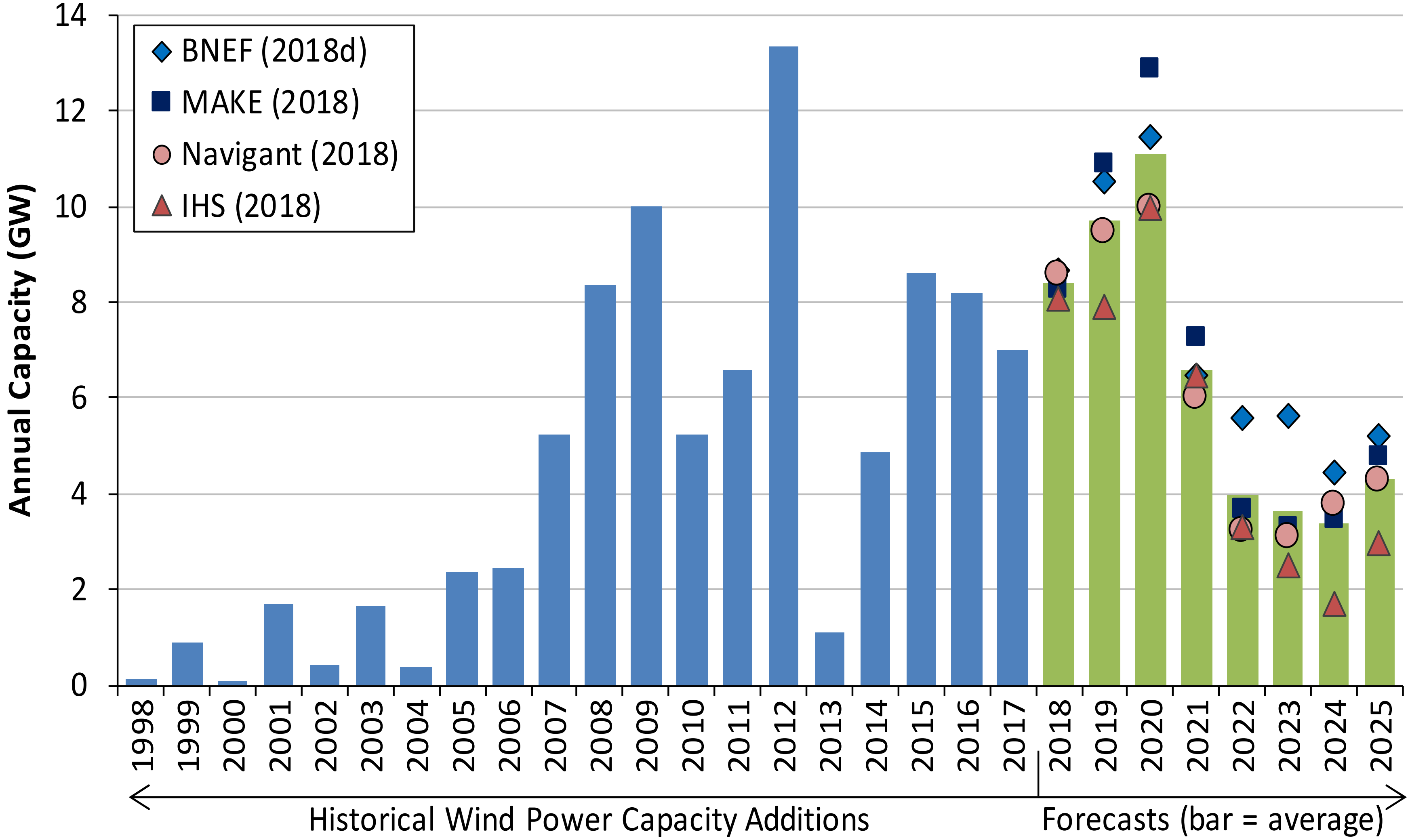
Notes: Because methods vary and a consistent set of operational impacts has not been included in each study, results from the different analyses of integration costs are not fully comparable.

Transmission Barriers Remain



Future Outlook

Sizable Wind Additions Anticipated for 2018–2020 Given Federal Tax Incentives; Downturn and Uncertainty Beyond 2020



- **Wind additions through 2020 consistent with deployment trajectory analyzed in DOE's Wind Vision report; not so after 2020**

Future Outlook, Beyond Current PTC Cycle, is Uncertain

Current Low Prices for Wind, Future Technological Advancement, and Direct Retail Sales May Support Higher Growth in Future, but Headwinds Include:

- Phase-out of federal tax incentives
- Continued low natural gas and wholesale electricity prices
- Potential decline in market value as wind penetration increases
- Modest electricity demand growth
- Limited near-term demand from state RPS policies
- Limited transmission infrastructure in some areas
- Growing competition from solar in some regions

Conclusions

- Wind capacity additions continued at a rapid pace in 2017, with significant additional new builds anticipated over next three years in part due to PTC
- Wind has been a significant source of new electric generation capacity additions in the U.S. in recent years
- Supply chain is diverse and multifaceted, with strong domestic content for nacelle assembly, towers, and blades
- Turbine scaling is significantly boosting wind project performance, while the installed cost of wind projects has declined
- Wind power sales prices are at all-time lows, enabling economic competitiveness (with the PTC) despite low natural gas prices
- Growth beyond current PTC cycle remains uncertain: could be blunted by declining federal tax support, expectations for low natural gas prices and solar costs, and modest electricity demand growth

For More Information

See full report for additional findings, a discussion of the sources of data used, etc.:

- windreport.lbl.gov

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